Westinghouse Non-Proprietary Class 3

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Structural Integrity Evaluation of Reactor Vessel Upper Head Penetrations to Support Continued Operation: Turkey Point Units 3&4

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March 2003

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1 INTRODUCTION

In September of 1991, a leak was discovered in the Reactor Vessel Control Rod Drive Mechanism (CRDM) head penetration region of an operating plant. This has led to the question of whether such a leak could occur at the Turkey Point Units 3&4 Control Rod Drive Mechanism (CRDM) or head vent nozzle penetrations. The geometry of interest is shown in Figure 1-1. Throughout this report, the penetration rows have been identified by their angle of intersection with the head. The location of head penetrations for Turkey Point Units 3&4 are shown in Figure 1-2 and the angles for each penetration are identified in Table 1-1.

The CRDM leak resulted from cracking in Alloy 600 base metal, which occurred in the outermost penetrations of a number of operating plants as discussed in Section 2. This outermost CRDM location, as well as a number of intermediate CRDM locations and the head vent were chosen for fracture mechanics analyses to support continued safe operation of Turkey Point Units 3&4 if such cracking were to be found. The dimensions of the CRDM penetrations are all identical, with a 4.00 inch Outside Diameter (OD) and a wall thickness of 0.625 inch [11C]. The head vent OD is 1.014 inch and the wall thickness is 0.122 inch [11A, 11B]. All of these dimensions are summarized in Table 6-2.

The basis of the fracture analysis was a detailed three-dimensional elastic-plastic finite element analysis of several penetration locations, as described in detail in Section 5. The fracture analysis was carried out using crack growth rates recommended by the EPRI Materials Reliability Program (MRP). These rates are consistent with service experience. The results are presented in the form of flaw tolerance charts for both surface and through wall flaws. If indications are found, the charts will determine the allowable service life of safe operation. The service life calculated in the flaw tolerance charts are all in Effective Full Power Years (EFPY).

Note that there are several locations in this report where Non-Proprietary information has been identified and bracketed. For each of the bracketed locations, reasons for Non-Proprietary classifications are given using a standardized system. The Non-Proprietary brackets are labeled with three different letters to provide this information. The explanation for each letter is given below:

a. The information reveals the distinguishing aspects of a process or component, structure, tool, method, etc., and the prevention of its use by Westinghouse's competitors, without license from Westinghouse, gives Westinghouse a competitive economic advantage.

b. The information, if used by a competitor, would reduce the competitor's expenditure of resources or improve the competitor's advantage in the design, manufacture, shipment, installation, assurance of quality, or licensing of a similar product.

c. The information reveals aspects of past, present, or future Westinghouse or customer funded development plans and programs of potential commercial value to Westinghouse.

The Non-Proprietary information is deleted in this, the unclassified version, of the report WCAP-16027-P Revision 0.

Table 1-1	Turkey Point Units 3&4 Head Penetration Nozzles with the Intersection Angles Identified									
Nozzle No.	Type	Angle (Degrees)		Nozzle No.	Type	Angle (Degrees)		Nozzle No.	Type	Angle (Degrees)
1	CRDM	0.0		23	CRDM	25.4		45	CRDM	33.1
2	CRDM	8.7		24	CRDM	25.4		46	CRDM	37.3
3	CRDM	8.7		25	CRDM	25.4		47	CRDM	37.3
4	CRDM	8.7		26	CRDM	27.0		48	CRDM	37.3
5	CRDM	8.7		27	CRDM	27.0		49	CRDM	37.3
6	CRDM	12.4		28	CRDM	27.0		51	CRDM	38.6
7	CRDM	12.4		29	CRDM	27.0		53	CRDM	38.6
8	CRDM	12.4		30	CRDM	28.6		55	CRDM	38.6
9	CRDM	12.4		31	CRDM	28.6		57	CRDM	38.6
10	CRDM	17.6		32	CRDM	28.6		58	CRDM	40.0
11	CRDM	17.6		33	CRDM	28.6		59	CRDM	40.0
12	CRDM	17.6		34	CRDM	28.6		60	CRDM	40.0
13	CRDM	17.6		35	CRDM	28.6		61	CRDM	40.0
14	CRDM	19.8		36	CRDM	28.6		62	CRDM	42.6
15	CRDM	19.8		37	CRDM	28.6		63	CRDM	42.6
16	CRDM	19.8		38	CRDM	33.1		64	CRDM	42.6
17	CRDM	19.8		39	CRDM	33.1		65	CRDM	42.6
18	CRDM	19.8		40	CRDM	33.1		66	CRDM	42.6
19	CRDM	19.8		41	CRDM	33.1		67	CRDM	42.6
20	CRDM	19.8		42	CRDM	33.1		68	CRDM	42.6
21	CRDM	19.8		43	CRDM	33.1		69	CRDM	42.6
22	CRDM	25.4		44	CRDM	33.1				

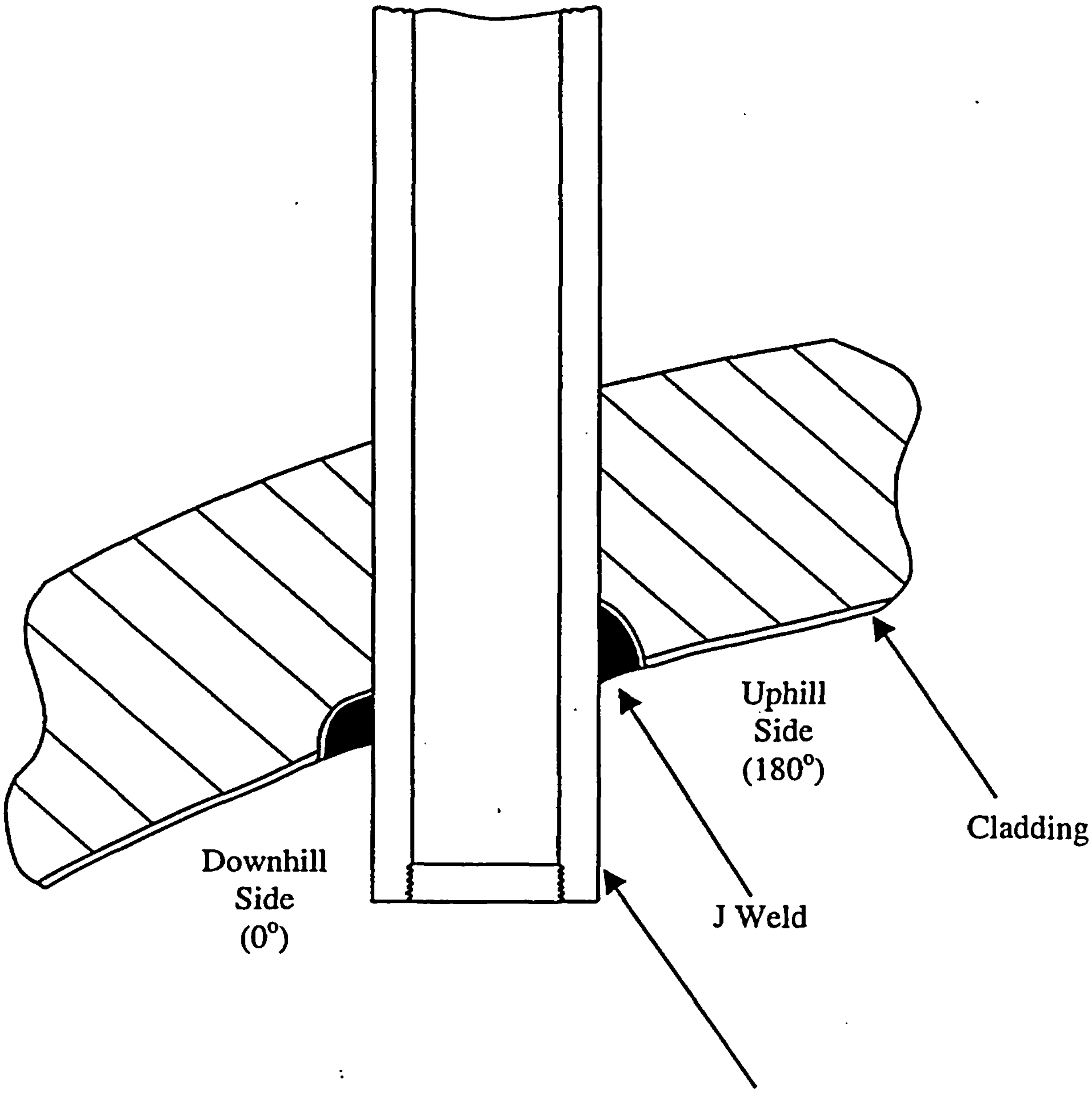

Figure 1-1 Reactor Vessel Control Rod Drive Mechanism (CRDM) Penetration

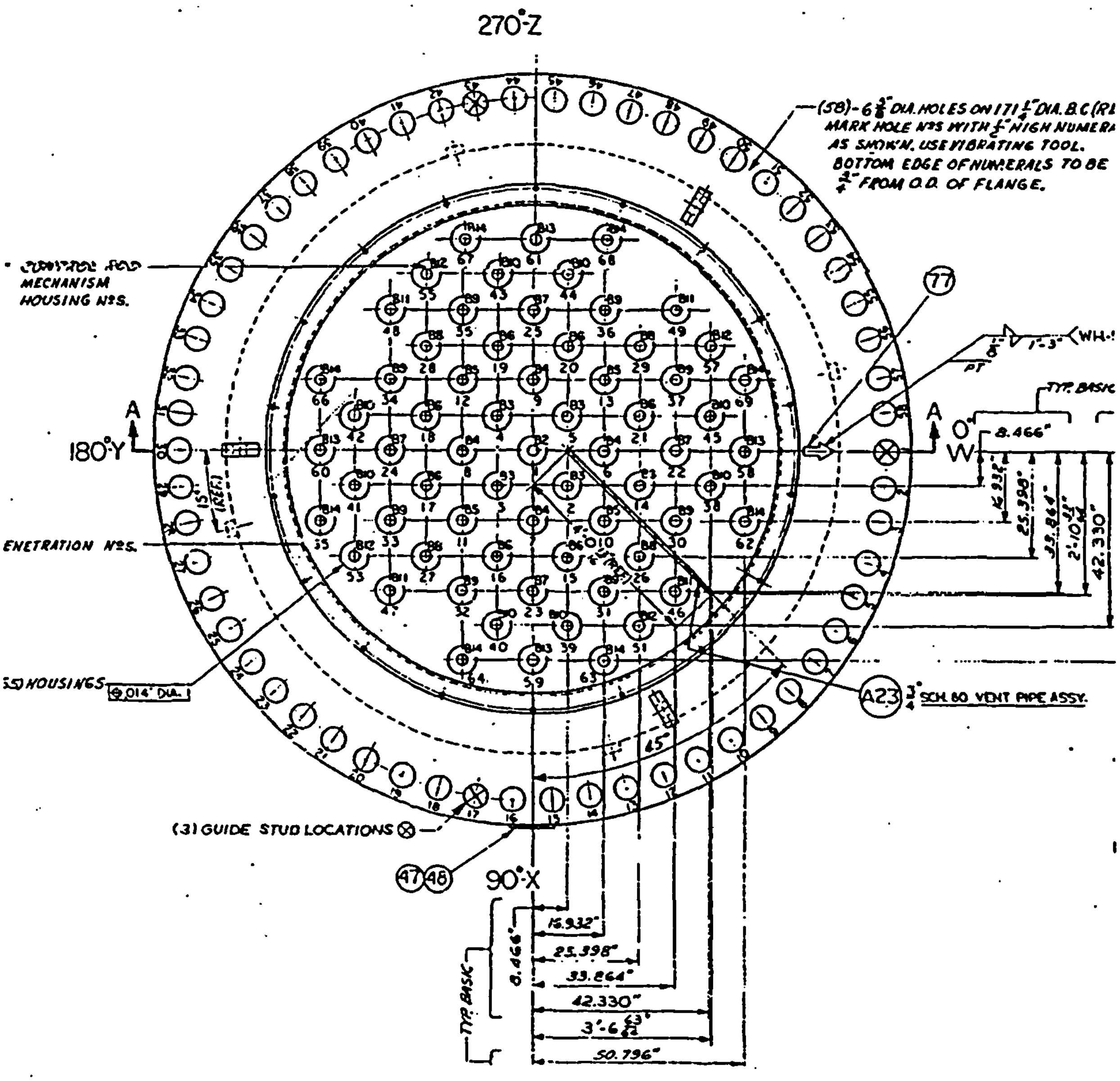

Figure 1-2 Location of Head Penetrations for Turkey Point Units 3&4

2 HISTORY OF CRACKING IN HEAD PENETRATIONS

In September of 1991, leakage was reported from the reactor vessel CRDM head penetration region of a French plant, Bugey Unit 3. Bugey 3 is a 920 megawatt three-loop Pressurized Water Reactor (PWR) plant which had just completed its tenth fuel cycle. The leak occurred during a post ten year hydrotest conducted at a pressure of approximately 3000 psi (204 bar) and a temperature of 194°F (90°C). The leak was detected by metal microphones, which are located on the top and bottom heads. The leak rate was estimated to be approximately 0.7 liter/hour. The location of the leak was subsequently established on a peripheral penetration with an active control rod (H-14), as seen in Figure 2-1.

The control rod drive mechanism and thermal sleeve were removed from this location to allow further examination. A study of the head penetration revealed the presence of longitudinal cracks near the head penetration attachment weld. Penetrant and ultrasonic testing confirmed the cracks. The cracked penetration was fabricated from Alloy 600 bar stock (SB-166), and has an outside diameter of 4 inches (10.16 cm) and an inside diameter of 2.75 inches (7.0 cm).

As a result of this finding, all of the control rod drive mechanisms and thermal sleeves at Bugey 3 were removed for inspection of the head penetrations. Only two penetrations were found to have cracks, as shown in Figure 2-1.

An inspection of a sample of penetrations at three additional plants were planned and conducted during the winter of 1991-92. These plants were Bugey 4 , Fessenheim 1, and Paluel 3. The three outermost rows of penetrations at each of these plants were examined, and further cracking was found in two of the three plants.

At Bugey 4, eight of the 64 penetrations examined were found to contain axial cracks, while only one of the 26 penetrations examined at Fessenheim 1 was cracked. The locations of all the cracked penetrations are shown in Figure 2-1. At the time, none of the 17 CRDM penetrations inspected at Paluel 3 showed indications of cracking, however subsequent inspections of the French plants have confirmed at least one crack in each operating plant.

Thus far, the cracking in reactor vessel heads not designed by Babcock and Wilcox (B&W) has been consistent in both its location and extent. All cracks discovered by nondestructive examination have been oriented axially, and have been located in the bottom portion of the penetration in the vicinity of the partial penetration attachment weld to the vessel head as shown schematically in Figure 1-1.

[

]a.c.e

[

]a,c,e

Non-destructive examinations of the leaking CRDM nozzles showed that most of the cracks were axially oriented, originating on the outside surface of the nozzles below the J-groove weld and propagating primarily in the nozzle base material to an elevation above the top of the J-groove weld. Leakage could then pass through the annulus to the top of the head where it was detected by visual inspection. In some cases the cracks initiated in the weld metal or propagated into the weld metal, and in a few cases the cracks propagated through the nozzle wall thickness to the inside surface.

[

]a,c,e

[

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The cracking has now been confirmed to be primary water stress corrosion cracking. Relatively high residual stresses are produced in the outermost CRDM penetrations due to the welding process. Other important factors which affect this process are temperature and time, with higher temperatures and longer times being more detrimental. The inspection findings for the plants examined through April 30th, 2002 are summarized in Table 2-1.

Table 2-1 Operational Information and Inspection Results for Units Examined (Results through April 30, 2002)

Country	Plant Type	Units Inspected	K Hours	Head Temp. (°F)	Total Penetrations	Penetrations Inspected	Penetrations With Indications
France	CPO	6	80-107	596-599	390	390	23
	CPY	28	42-97	552	1820	1820	126
	1300MW	20	32-51	558-597	1542	1542	95
Sweden	3 Loop	3	75-115	580-606	195	190	8
Switzerland	2 Loop	2	148-154	575	72	72	2
Japan	2 Loop	7	105-108	590-599	276	243	0
	3 Loop	7	99	610	455	398	0
	4 Loop	3	46	590	229	193	0
Belgium	2 Loop	2	115	588	98	98	0
	3 Loop	5	60-120	554-603	337	337	6
Spain	3 Loop	5	65-70	610	325	102	0
Brazil	2 Loop	1	25	NA	40	40	0
South Africa	3 Loop	1	NA	NA	65	65	6
Slovenia	2 Loop	1	NA	NA	49	49	0
South Korea	2 Loop	3	NA	NA	49	49	3
	3 Loop	2	NA	NA	130	130	2
US	2 Loop	2	170	590	98	98	0
	3 Loop	1	NA	NA	65	20	12
	4 Loop	18	NA	NA	1149	537	35
TOTALS		117	–	–	7384	6373	318

NA = Not Available.

Note: CPY and CPO are both 900 MW reactors.

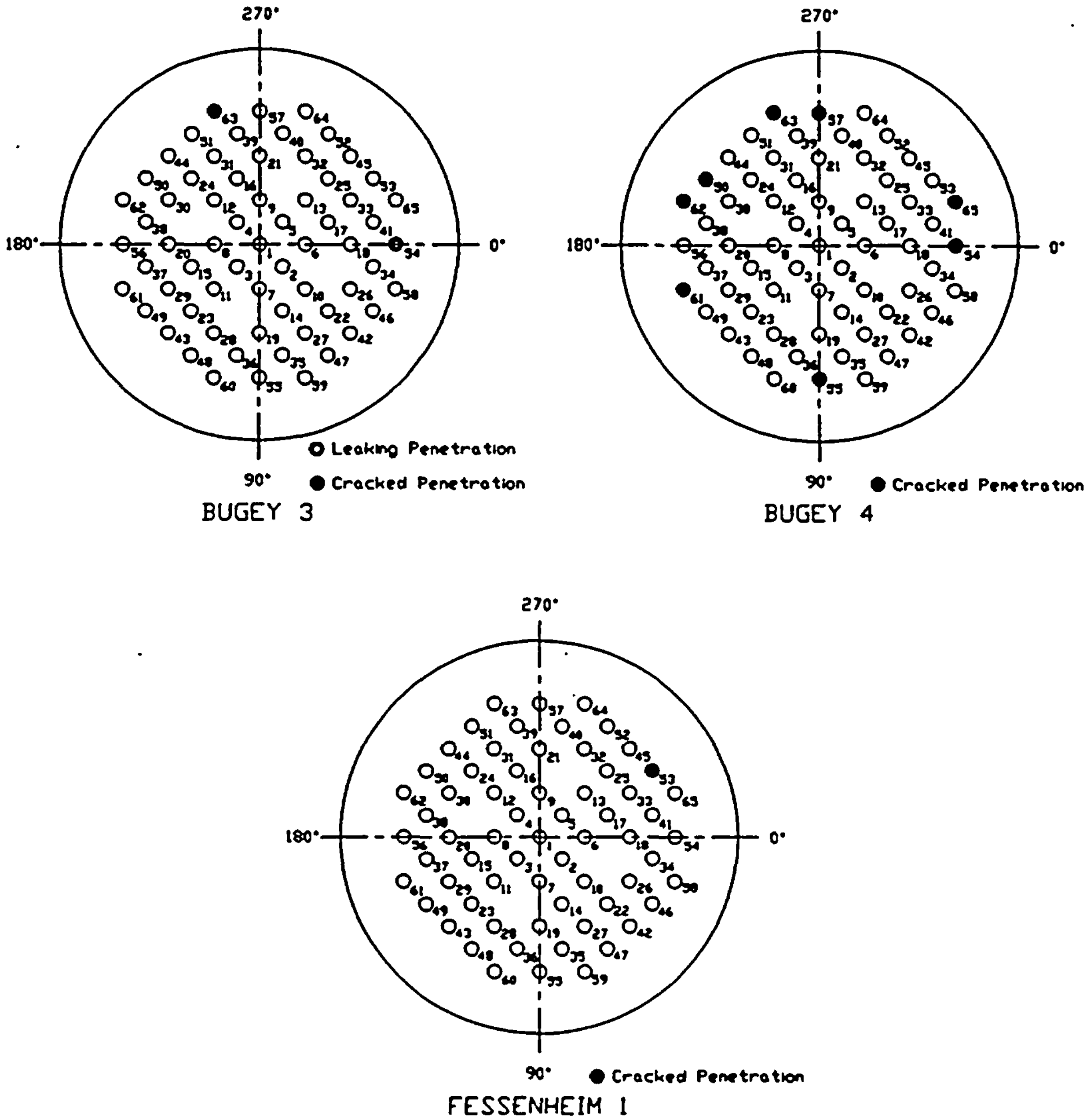

Figure 2-1 EDF Plant R/V Closure Head CRDM Penetrations – Penetrations with Cracking

3 OVERALL TECHNICAL APPROACH

The primary goal of this work is to provide technical justification for the continued safe operation of Turkey Point Units 3&4 in the event that cracking is discovered during in-service inspections of the Alloy 600 reactor vessel upper head penetrations.

3.1 PENETRATION STRESS ANALYSIS

Three-dimensional elastic-plastic finite element stress analyses applicable to Turkey Point Units 3&4 was performed to determine the stresses in the head penetration region [6, 11A, 11B, 11C, 11D, 11E]. These analyses have considered pressure loads associated with steady state operation, as well as the residual stresses that are produced by the fabrication process.

[

]a,c,e

3.2 FLAW TOLERANCE APPROACH

A flaw tolerance approach has been developed to allow continued safe operation until an appropriate time for repair, or the end of plant life. The approach is based on the prediction of future growth of detected flaws, to ensure that such flaws would remain stable.

If an indication is discovered during in-service inspection, its size can be compared with the flaw size considered as allowable for continued service. This "allowable" flaw size is determined from the actual loading (including mechanical and residual loads) on the head penetration for Turkey Point Units 3&4. Acceptance criteria are discussed in Section 6.5.

The time for the observed crack to reach the allowable crack size determines the length of time the plant can remain online before repair, if required. For the crack growth calculation, a best estimate is needed and no additional margins are necessary.

The results of the evaluation are presented in terms of simple flaw tolerance charts. The charts graphically show the time required to reach the allowable length or depth, which represents additional service life before repair. This result is a function of the loading on the particular head penetration as well as the circumferential location of the crack in the penetration nozzle.

Schematic drawings of the head penetration flaw tolerance charts are presented as Figures 3-1 and 3-2. These two types of charts can be used to provide estimates of the remaining service life before a leak would develop from an observed crack. For example, if a part-through flaw was discovered, the user would first refer to Figure 3-1, to determine the time (t_P) which would be remaining before the crack would penetrate the wall or reach the allowable depth (t_a) (e.g. a/t = 0.75). Once the crack penetrates the wall, the time (t_B) required to reach an allowable crack length would be determined from Figure 3-2. The total time remaining would then be the simple sum:

$$\text{Time remaining} = t_P + t_B$$

Another way to determine the allowable time of operation with a part-through flaw would be to use Figure 3-2 directly, in effect assuming the part-through flaw is a through-wall flaw. This approach would be more conservative than that above, and the time remaining would then be:

$$\text{Time remaining} = t_B$$

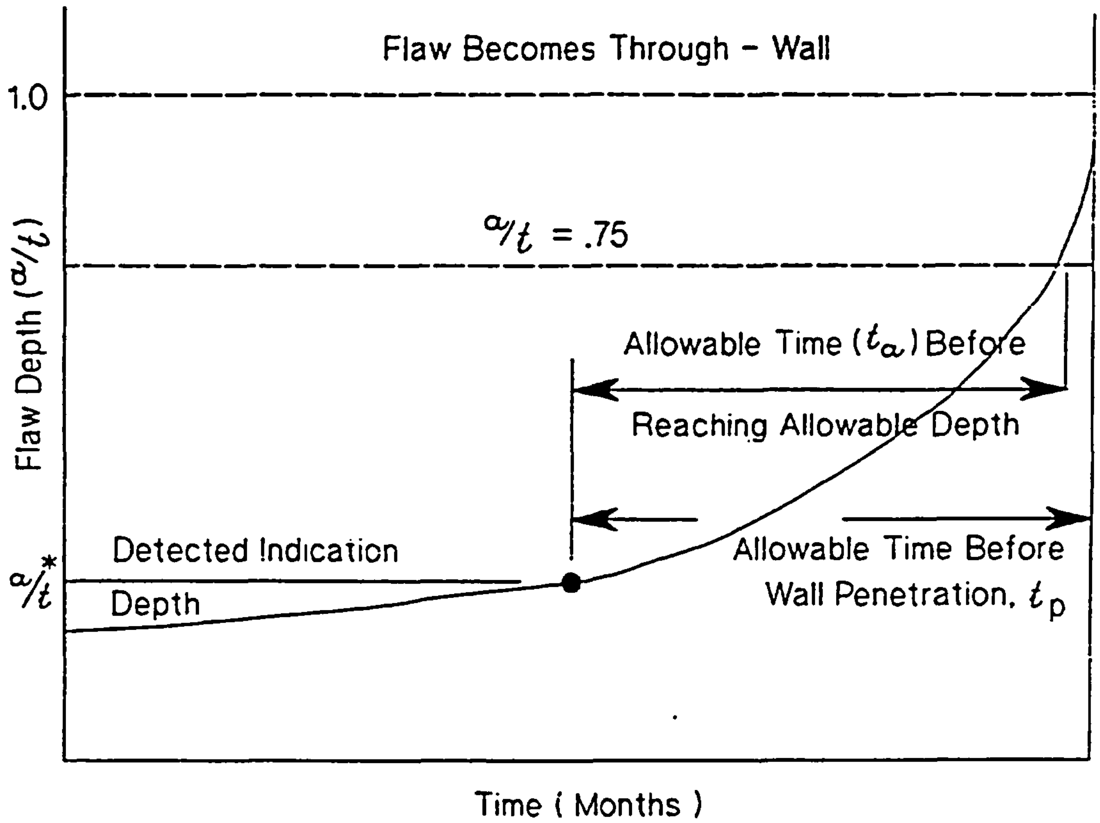

Figure 3-1 Schematic of a Head Penetration Flaw Growth Chart for Part-Through Flaws

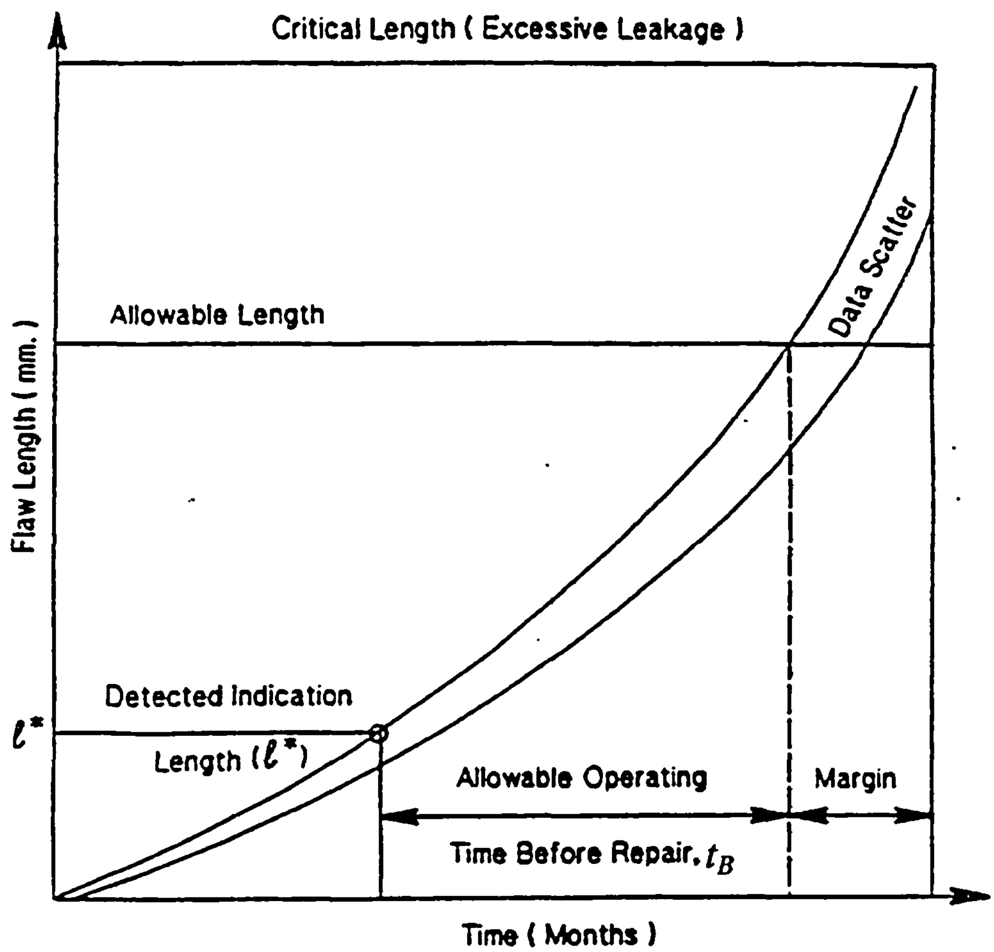

Figure 3-2 Schematic of a Head Penetration Flaw Tolerance Chart for Through-Wall Flaws

4 MATERIAL PROPERTIES, FABRICATION HISTORY AND CRACK GROWTH PREDICTION

4.1 MATERIALS AND FABRICATION

The head adapters for Turkey Point Units 3&4 were produced by Huntington Alloys in the USA. The carbon content and mechanical properties of the Alloy 600 material used to fabricate the Turkey Point Units 3&4 vessel are provided in Table 4-1. The Certified Material Test Reports (CMTRs) were used to obtain the chemistry and mechanical properties for the vessel head penetrations. The CMTRs for the material indicate a heat treatment of 1.5 hours at 1725°F, air-cooled. Figures 4-1 and 4-2 illustrate the yield strengths and carbon content based on percent of heats for Turkey Point Units 3&4 relative to a sample of the French head adapters that have experienced cracking. Note that Turkey Point Unit 3 and Turkey Point Unit 4 are identical in heat number, yield strength, and carbon content and are therefore enveloped together. The general trend for the head adapter penetrations in Turkey Point Units 3&4 are of a higher carbon content, higher mill annealing temperature, and lower yield strength relative to those on the French vessels. These factors should all have a beneficial effect on the material resistance to PWSCC in the head penetrations.

4.2 CRACK GROWTH PREDICTION

The cracks in the penetration region have been determined to result from primary water stress corrosion cracking in the Alloy 600 base metal and, in some cases, the Alloy 182 weld metal. There are a number of available measurements of static load crack growth rates in primary water environment, and in this section the available results will be compared and a representative growth rate established.

Direct measurements of Stress Corrosion Cracking (SCC) growth rates in Alloy 600 are relatively rare. Also, care should be used when interpreting the results because the materials may be excessively cold worked, or the loading applied may be near or exceeding the limit load of the penetration nozzle, meaning there will be an interaction between tearing and crack growth. In these cases the crack growth rates may not be representative of service conditions.

The effort to develop a reliable crack growth rate model for Alloy 600 began in the spring of 1992, when the Westinghouse Owners Group began to develop a safety case to support continued operation of plants. At the time, there was no available crack growth rate data for head penetration materials, and only a few publications existed on growth rates of Alloy 600 in any product form.

The best available publication at that time was that of Peter Scott of Framatome, who had developed a growth rate model for PWR steam generator materials [1]. His model was based on a study of results obtained by McIlree, Rebak and Smialowska [2] who had tested short steam generator tubes which had been flattened into thin compact specimens.

An equation was fitted to the data of reference [2] for the results obtained in water chemistries that fell within the standard specification for PWR primary water. Results for chemistries outside the specification were not used. The following equation was fitted to the data at 330°C (626°F):

$$\frac{da}{dt} = 2.8 \times 10^{-11} (K - 9)^{1.16} \text{ m/sec} \qquad (4\text{-}1)$$

where:

K is in $MPa\sqrt{m}$

The next step was to correct these results for the effects of cold work. Based on work by Cassagne and Gelpi [3], Scott concluded that dividing the above equation by a factor of 10 would be appropriate to account for the effects of cold work. The crack growth law for 330°C (626°F) then becomes:

$$\frac{da}{dt} = 2.8 \times 10^{-12} (K - 9)^{1.16} \text{ m/sec} \qquad (4\text{-}2)$$

Scott further corrected this law for the effects of temperature. This forms the basis for the PWR Materials Reliability Program (MRP) recommended crack growth rate (CGR) curve for the evaluation of SCC where a power-law dependence on stress intensity factor was assumed [4H]. The MRP recommended CGR curve was used in this report for determining the primary water stress corrosion crack growth rate and a brief discussion on this recommended curve is as follows:

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]a,c,e

There is a general agreement that crack growth in Alloy 600 materials in the primary water environment can be modeled using a power-law dependence on stress intensity factor with differences in temperature accounted for by an activation energy (Arrhenius) model for thermally controlled processes. Figure 4-3 shows the recommended CGR curve along with the laboratory data from Huntington materials used to develop the curve.

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]a,c,e

The applicability of the MRP recommended model to head penetrations was recently confirmed by two independent approaches. The first was a collection of all available data from Standard Steel and Huntington Alloys materials tested over the past ten years [4H]. The results are shown in Figure 4-3, along with the Scott model for the test temperature.

The MRP crack growth curve was structured to bound 75 percent of the 26 heats for which test results were available. Fits were done on the results for each heat, and the constant term was determined for each heat. This was done to eliminate the concern that the curve might be biased from a large number of results from a single heat. The 75th percentile was then determined from these results. The MRP expert panel on crack growth endorsed the resulting curve unanimously in a meeting on March 6th and 7th 2002. This approach is consistent with the Section XI flaw evaluation philosophy, which is to make a best estimate prediction of future growth of a flaw. Margins are incorporated in the allowable flaw sizes. The entire data set is shown in Figure 4-3, where the data have been adjusted to a single temperature of 325°C.

A second independent set of data were used to validate the model, and these data were obtained from the two inspections carried out on penetration no. 75 of D.C. Cook Unit 2, which was first found to be cracked in 1994 [4G]. The plant operated for one fuel cycle before the penetration was repaired in 1996 and the flaw was measured again before being repaired. These results were used to estimate the PWSCC growth rate for both the length of the flaw and its depth. These two points are also shown in Figure 4-4, and are consistent with the laboratory data for Huntington materials. In fact, Figure 4-4 demonstrates that the MRP model is nearly an upper bound for these materials. The D.C. Cook Unit 2 penetrations were made from Huntington materials.

Since Turkey Point Units 3&4 operate at a temperature of 312°C (594°F) in the head region [9], and the crack growth rate is strongly affected by temperature, a temperature adjustment is necessary. This temperature correction was obtained from study of both laboratory and field data for stress corrosion crack growth rates for Alloy 600 in primary water environments. The available data showing the effect of temperature are summarized in Figure 4-5. Most of the results shown here are from steam generator tube materials, with several sets of data from operating plants, and results from two heats of materials tested in a laboratory [4A].

Study of the data shown in Figure 4-5 results in an activation energy of 31-33 Kcal/mole, which can then be used to adjust for the lower operating temperature. This value is slightly lower than the generally accepted activation energy of 44-50 Kcal/mole used to characterize the effect of temperature on crack initiation, but the trend of the actual data for many different sources is unmistakable.

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]a,c,e

Therefore the following crack growth rate model was used for the Turkey Point Units 3&4 head penetration for crack growth in all the cases analyzed.

$$\frac{da}{dt} = 1.51 \times 10^{-12} (K - 9)^{1.16} \text{ m/sec}$$

where:

K = applied stress intensity factor, in $MPa\sqrt{m}$

This equation implies a threshold for cracking susceptibility, $K_{ISCC} = 9\ MPa\sqrt{m}$. The crack growth rate is applicable to propagation in both axial and circumferential directions.

(a,c,e)

Table 4-1 Turkey Point Units 3&4 Head Penetration Material Information

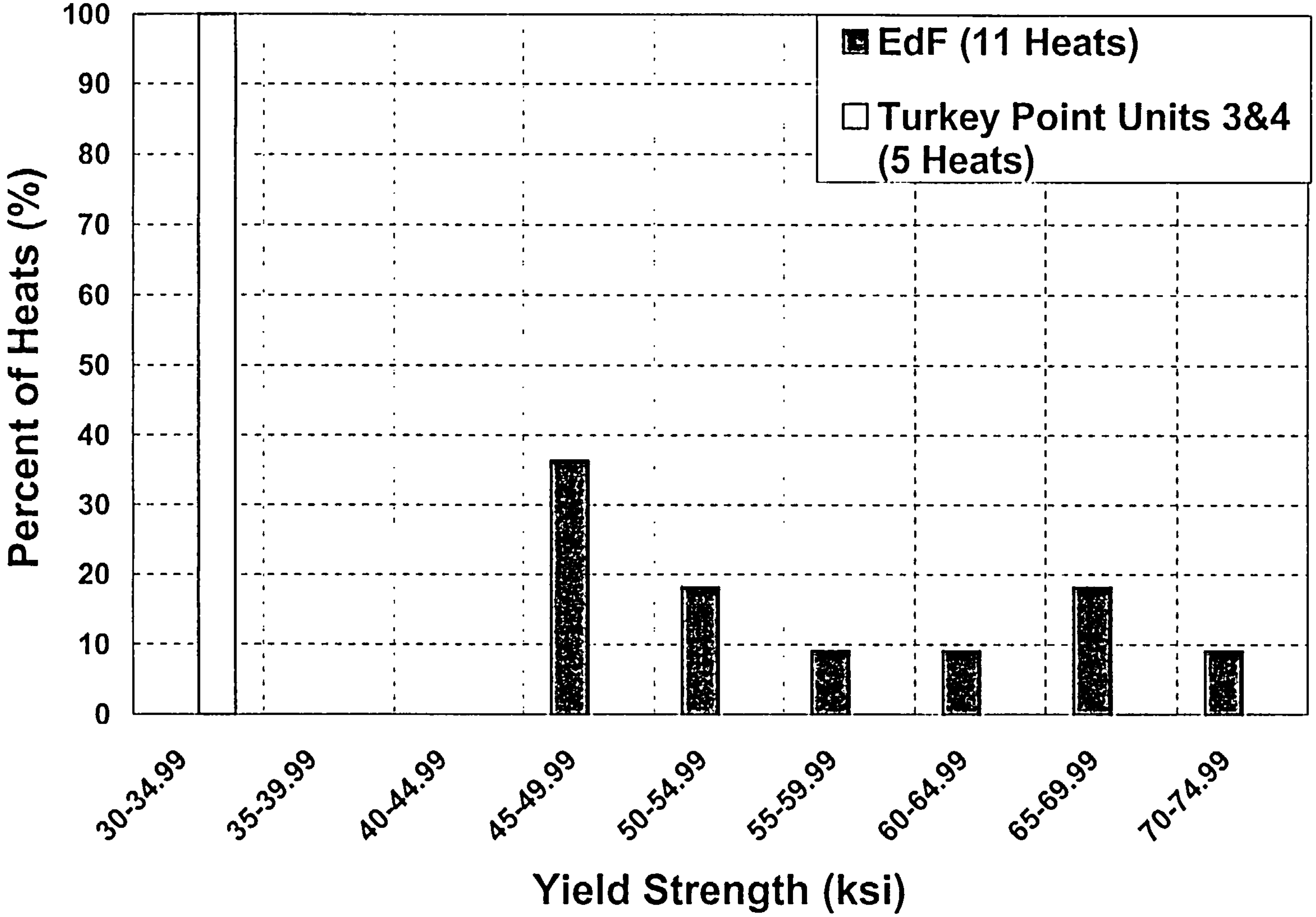


Figure 4-1 Yield Strength of the Various Heats of Alloy 600 Used in Fabricating the Turkey Point Units 3&4 and French Head Penetrations

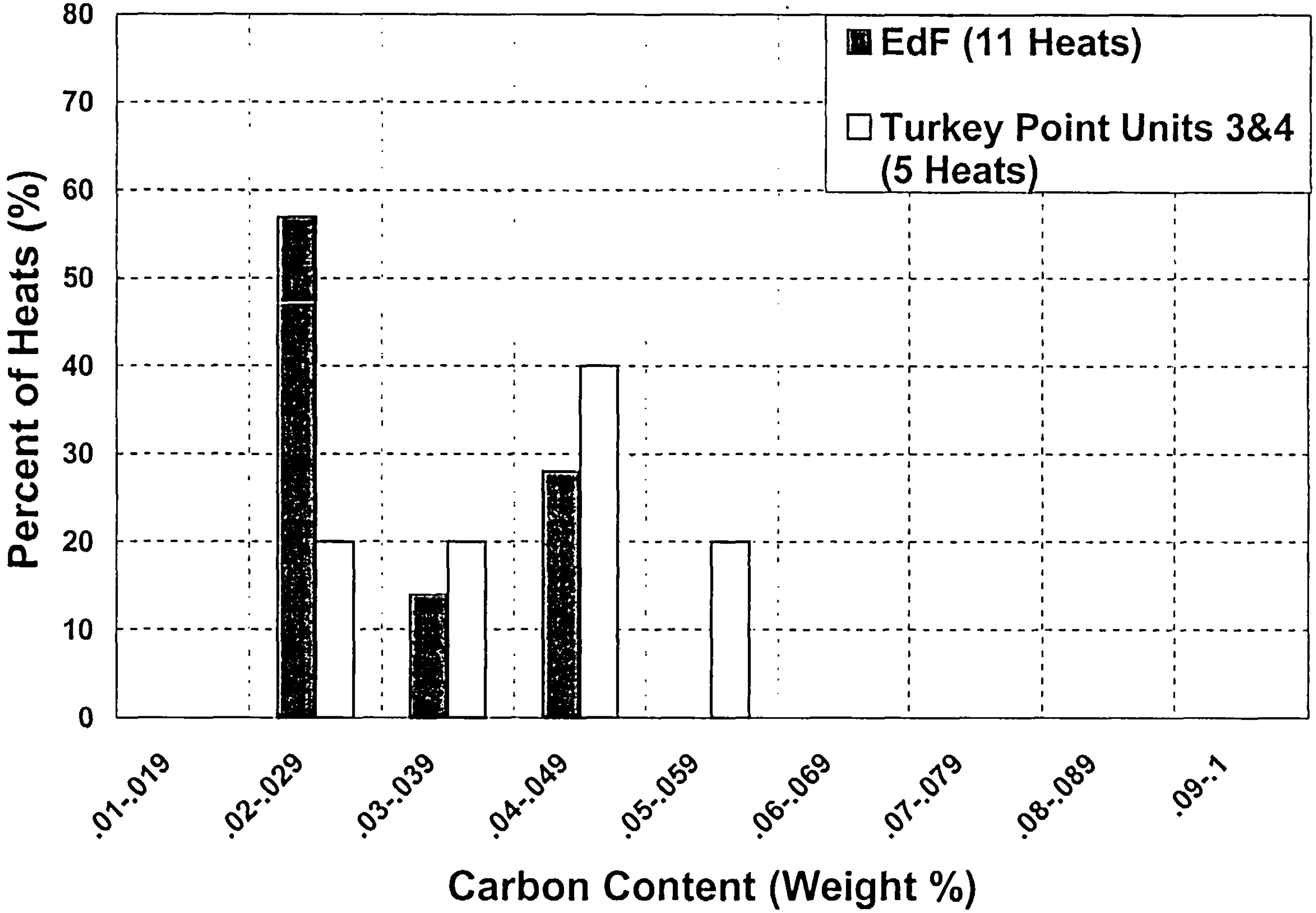


Figure 4-2 Carbon Content of the Various Heats of Alloy 600 Used in Fabricating the Turkey Point Units 3&4 and French Head Penetration

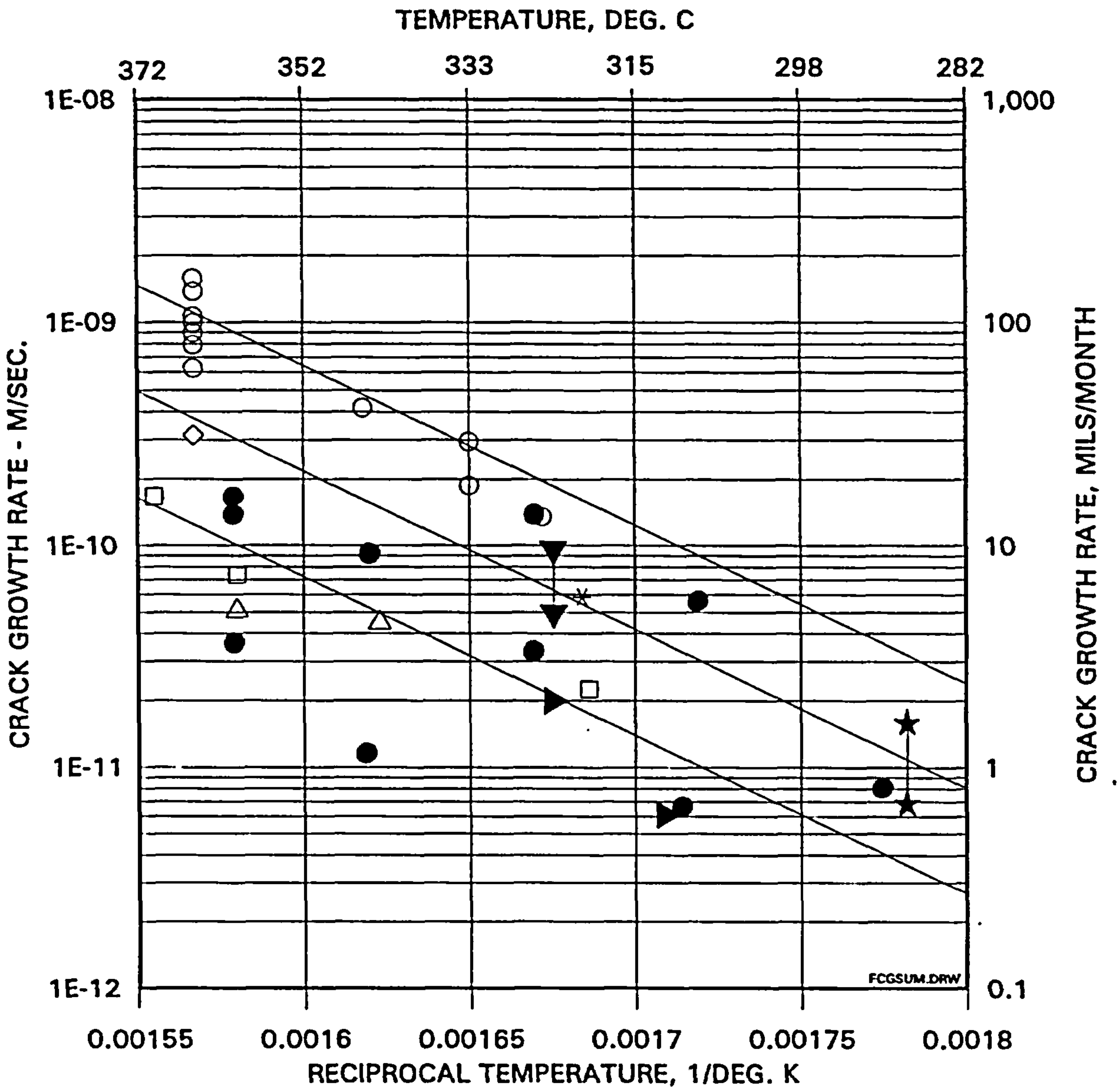
(a,c,e)

Figure 4-3 Screened Laboratory Data for Alloy 600 with the MRP Recommended Curve (Note that the Modified Scott Model is also Shown)

(a,c,e)

Note that the data have been normalized to a temperature of 325°C. The actual test temperatures are listed in parenthesis after the caption. For example, the Huntington data were obtained at temperatures ranging from 315°C to 331°C.

Figure 4-4 Model for PWSCC Growth Rates in Alloy 600 in Primary Water Environments (325°C), With Supporting Data from Standard Steel, Huntington, and Sandvik Materials



Note: All symbols are for steam generator materials, except the solid circles, which are head penetration laboratory data.

Figure 4-5 Summary of Temperature Effects on PWSCC Growth Rates for Alloy 600 in Primary Water

5 STRESS ANALYSIS

5.1 OBJECTIVES OF THE ANALYSIS

The objective of this analysis was to obtain accurate stresses in each of the CRDM and head vent penetrations as well as the immediate vicinity. To do so requires a three-dimensional finite element analysis which considers all the pertinent loading on the penetration [6]. An investigation of deformations at the lower end of the housing was also performed using the same model. Five CRDM locations were considered: the outermost row (42.6°), rows at 40.0°, 38.6°, 28.6°, and the center location (0°). These locations bound the CRDM penetration angles in the Turkey Point Units 3&4 reactor vessel head. In addition the head vent was analyzed.

The analyses were used to provide information for the flaw tolerance evaluation in Section 6. Also, the results of the stress analysis were compared to the findings from service experience to help assess the causes of the observed cracking.

5.2 MODEL

A three-dimensional finite element model comprised of isoparametric brick and wedge elements with mid-side nodes on each face was used to obtain the stresses and deflections. Views of the outermost CRDM and the head vent models are shown in Figures 5-1 and 5-2 respectively. Taking advantage of the symmetry of the vessel head, only half of the CRDM penetrations were modeled. Similarly, only half of the center penetration was modeled.

In the models, the lower portion of the Control Rod Drive Mechanism (CRDM) penetration nozzle, the head vent, the adjacent section of the vessel closure head, and the joining weld were modeled. The vessel to penetration nozzle weld was simulated with two layers of elements. The penetration nozzle, weld metal, and cladding were modeled as Alloy 600 and the vessel head shell as carbon steel.

The only loads used in the analysis are the steady state operating loads. External loads, such as seismic loads, have been studied and have no impact since the penetration nozzles are captured by the full thickness of the reactor vessel head (about 6 and 3/16 inches of steel [11A, 11B]) into which the penetrations are shrunk fit during construction. The area of interest is in the penetration near the attachment weld, which is unaffected by these external loads.

5.3 STRESS ANALYSIS RESULTS – OUTERMOST CRDM PENETRATION (42.6°)

Figure 5-3 presents the hoop and axial stresses for the steady state condition for the outermost penetration.

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]a,c,e

5.4 STRESS ANALYSIS RESULTS – INTERMEDIATE CRDM PENETRATIONS

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5.5 STRESS ANALYSIS RESULTS – CENTER CRDM PENETRATION

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]a,c,e

5.6 STRESS ANALYSIS RESULTS – HEAD VENT

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]a,c,e

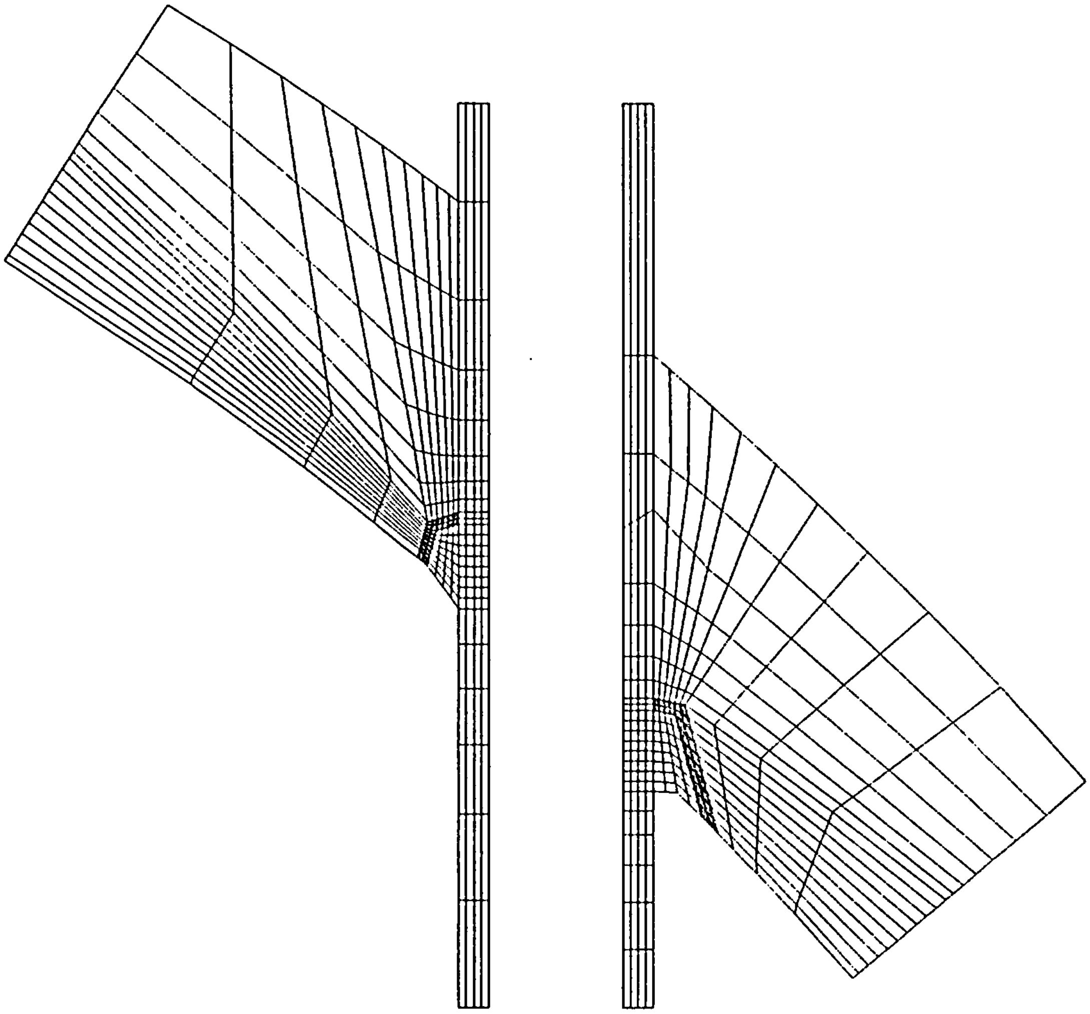


Figure 5-1 Finite Element Model of the Outermost CRDM Penetration (42.6 Degrees)

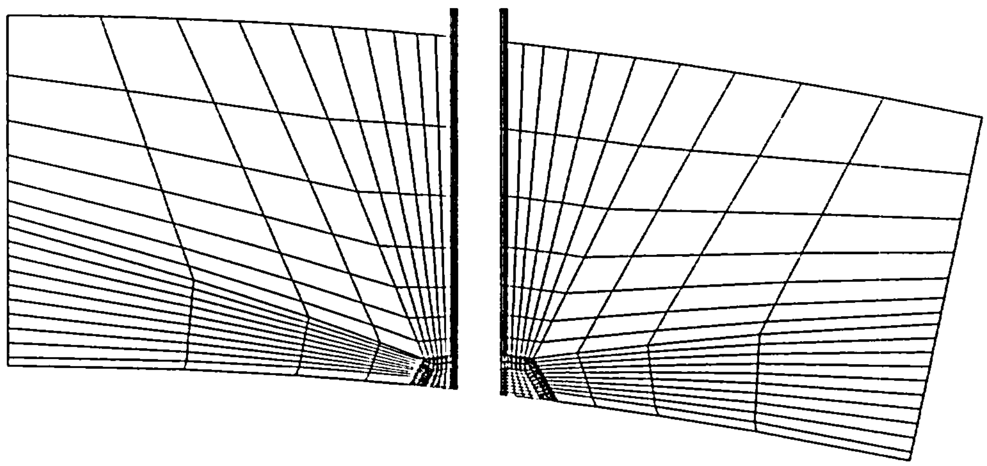
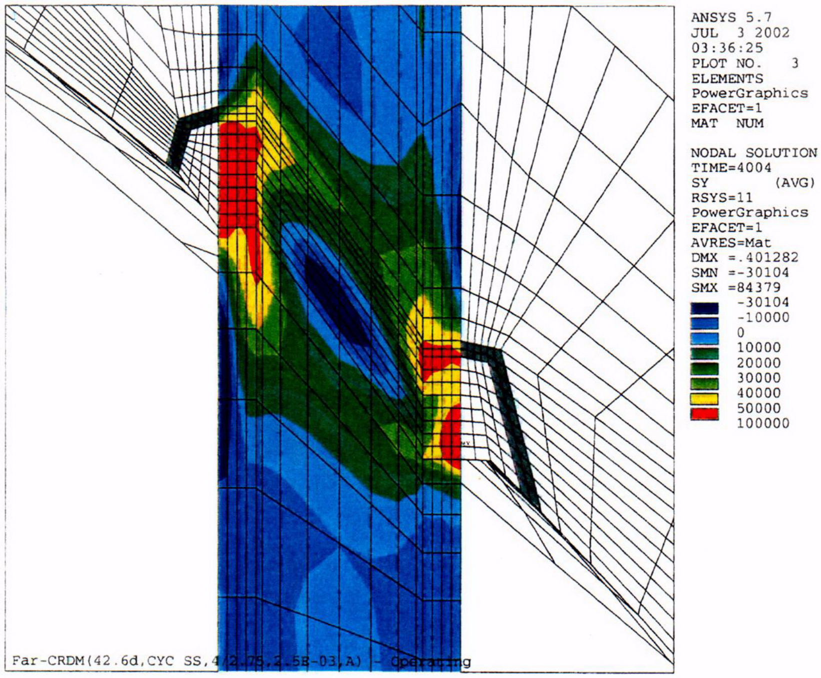


Figure 5-2 Vent Pipe Finite Element Model



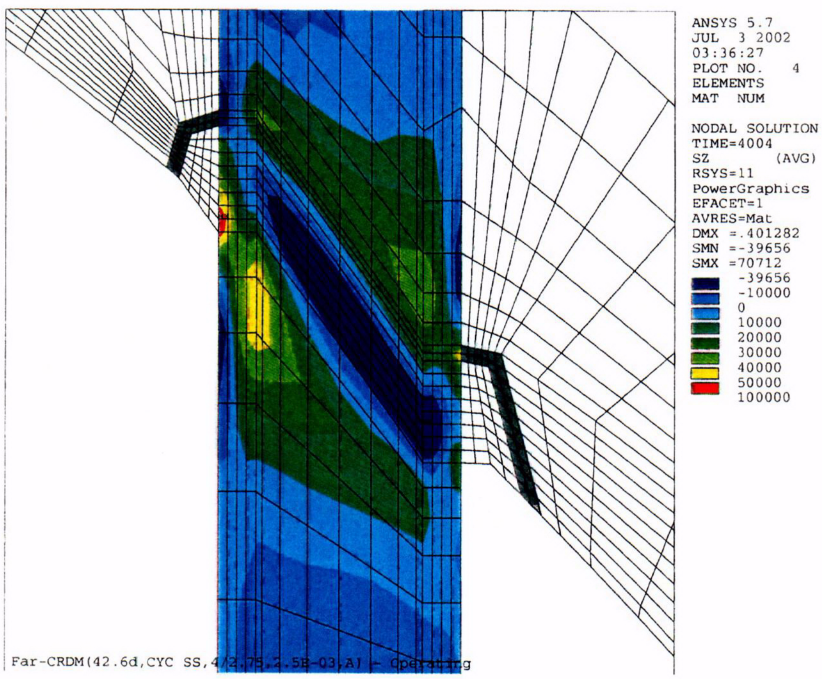
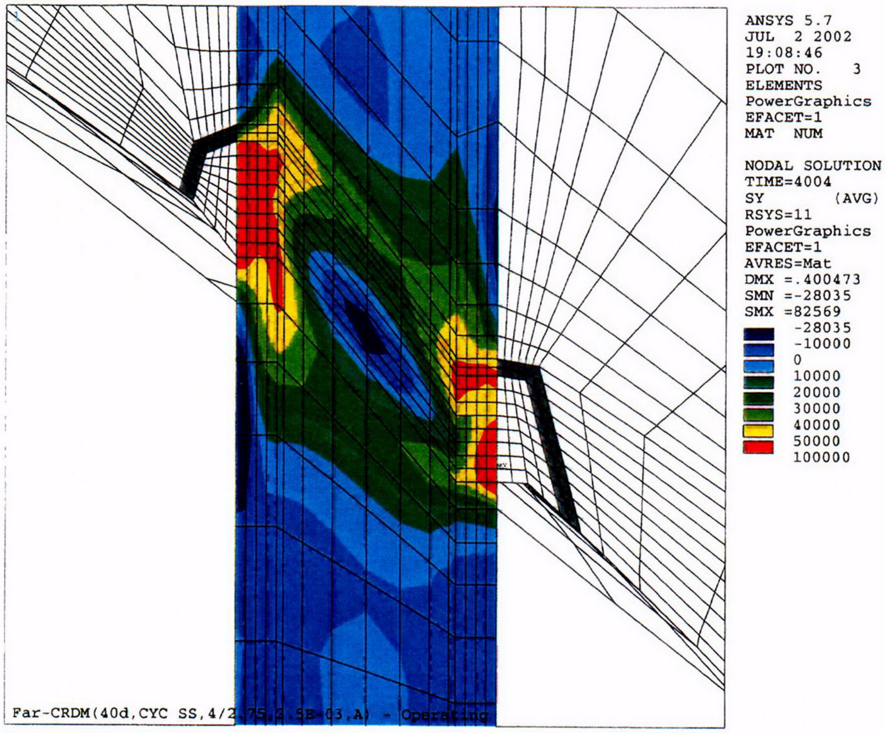


Figure 5-3 Stress Distribution at Steady State Condition: Outermost CRDM Penetration Nozzle (42.6 Degrees) (Hoop Stress is the Top Figure, Axial Stress is the Bottom Figure)

C01



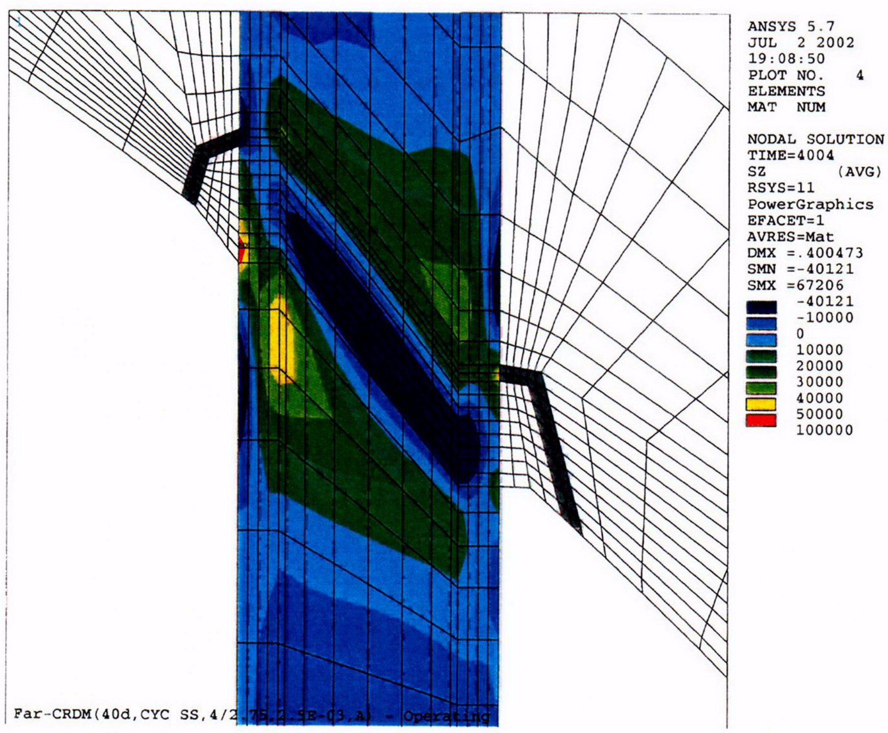


Figure 5-4 Stress Distributions at Steady State Conditions for the 40.0 Degree CRDM Penetration Nozzle (Hoop Stress is the Top Figure; Axial Stress is the Bottom Figure)

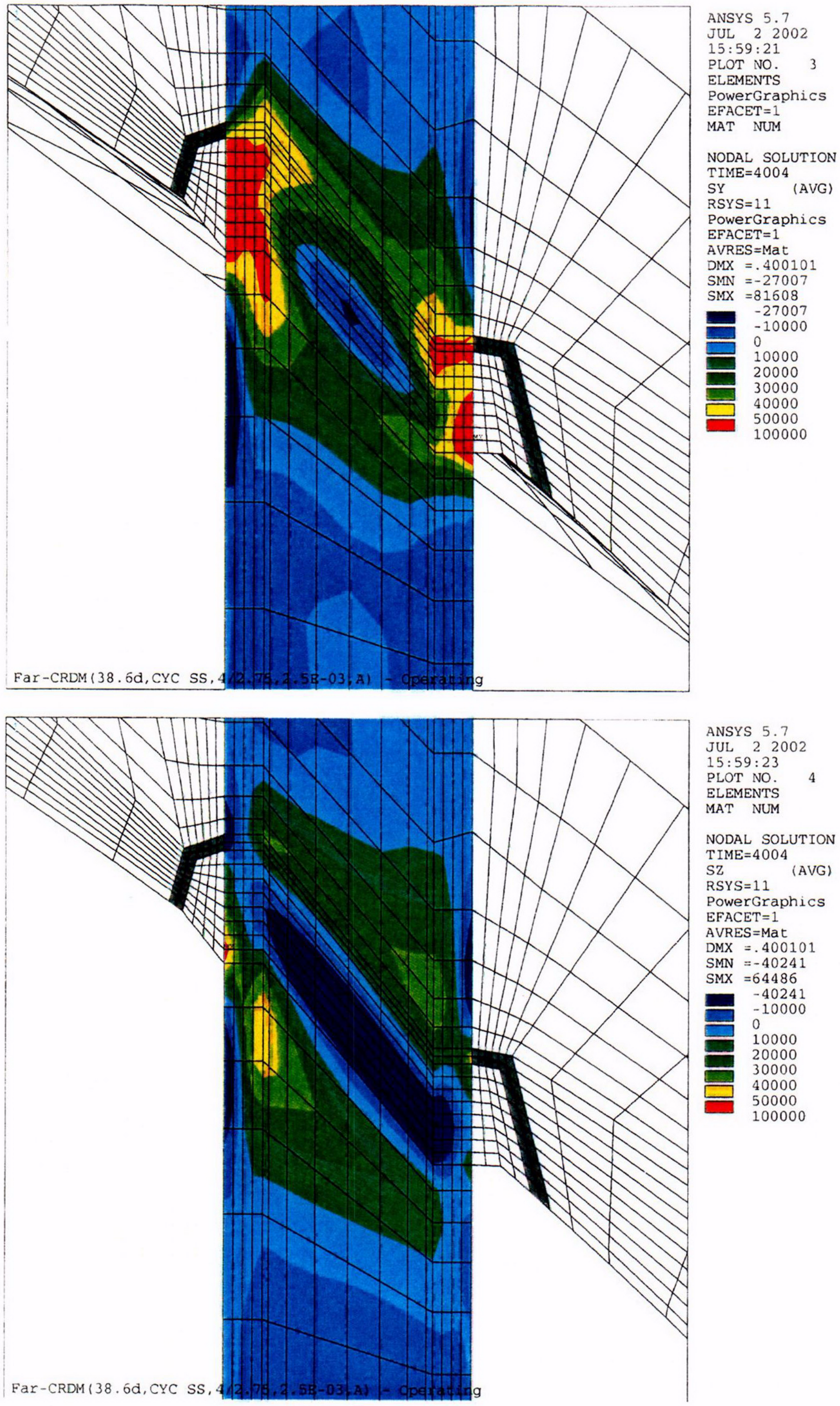


Figure 5-5 Stress Distribution at Steady State Conditions for the 38.6 Degrees CRDM Penetration (Hoop Stress is the Top Figure; Axial Stress is the Bottom Figure)

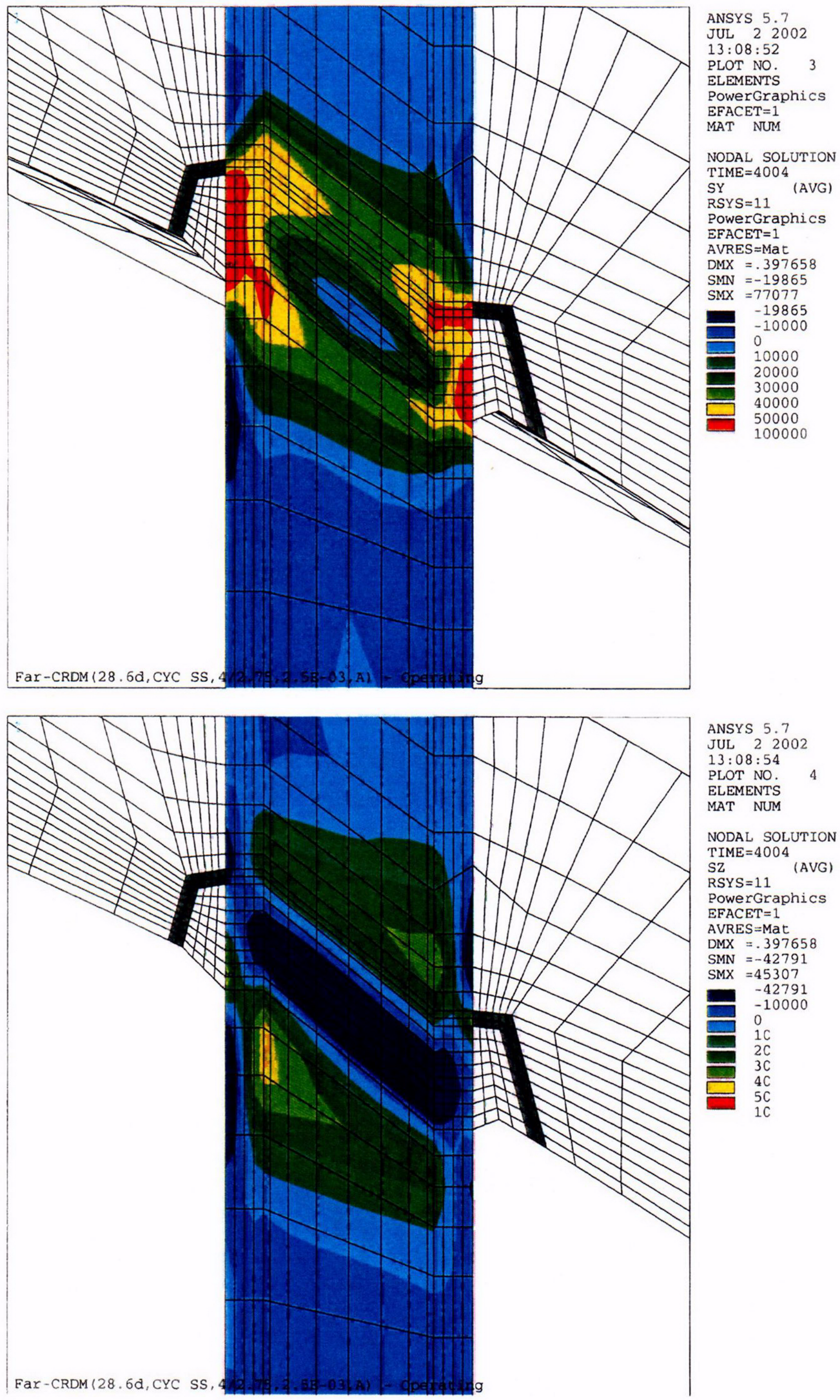


Figure 5-6 Stress Distribution at Steady State Conditions for the 28.6 Degrees CRDM Penetration (Hoop Stress is the Top Figure; Axial Stress is the Bottom Figure)

C04

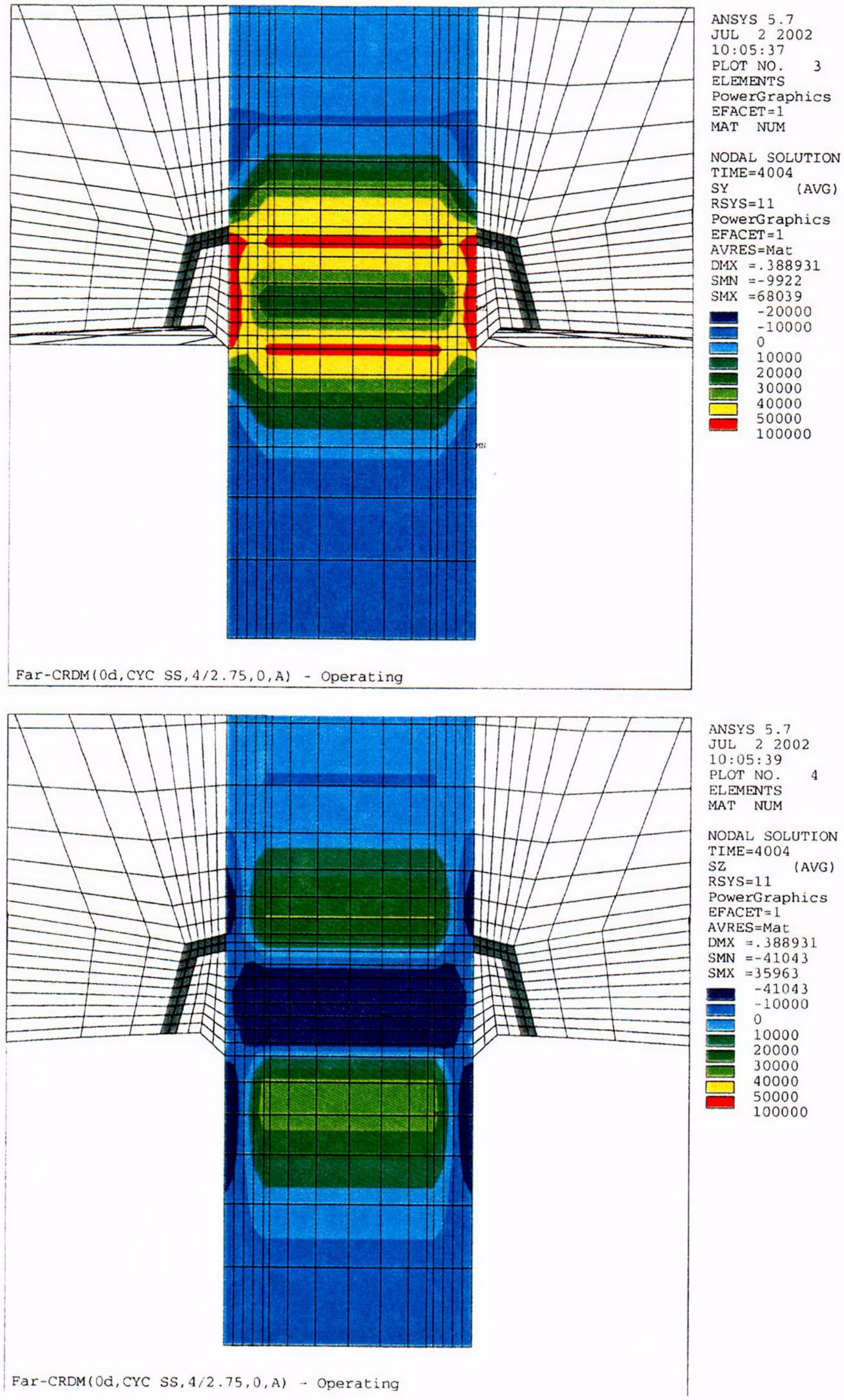
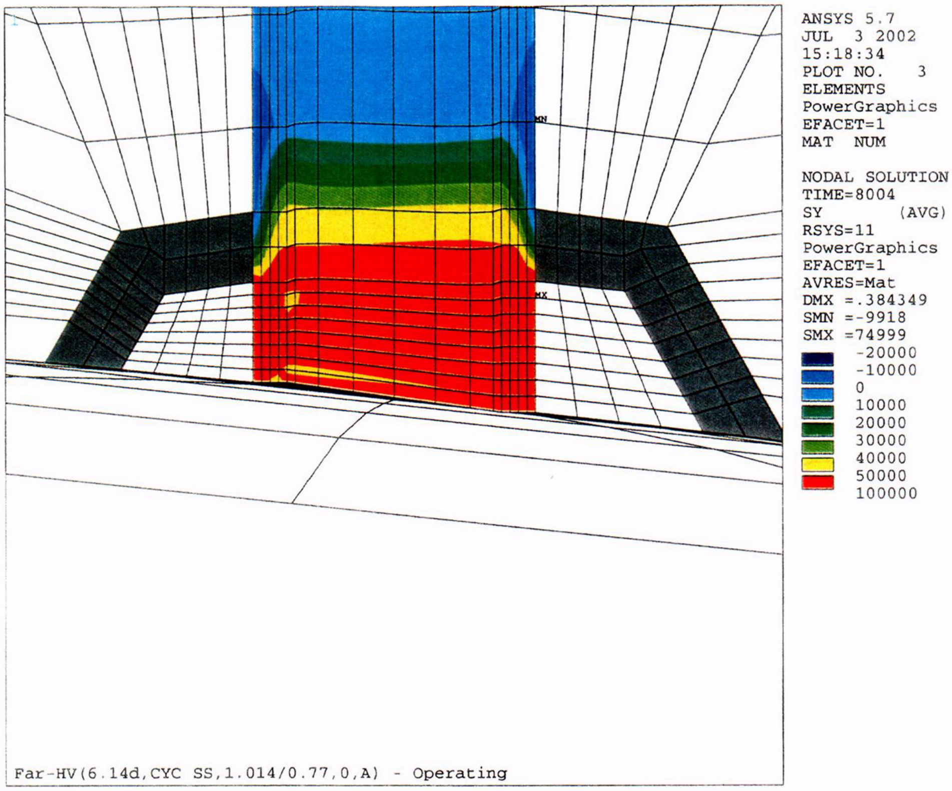


Figure 5-7 Stress Distribution at Steady State Conditions for the Center CRDM Penetration (Hoop Stress is the Top Figure; Axial Stress is the Bottom Figure)

CO5



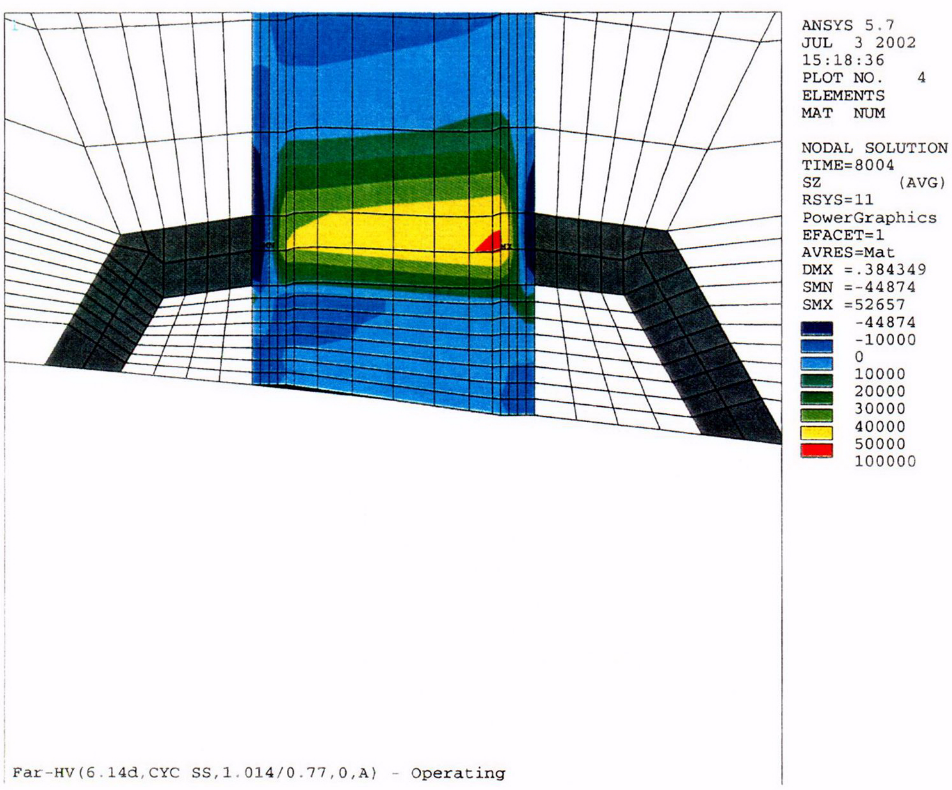


Figure 5-8 Stress Contours in the Head Vent Nozzle as a Result of Residual Stresses and Operating Pressure (Hoop Stress is the Top Figure; Axial Stress is the Bottom Figure)

C06

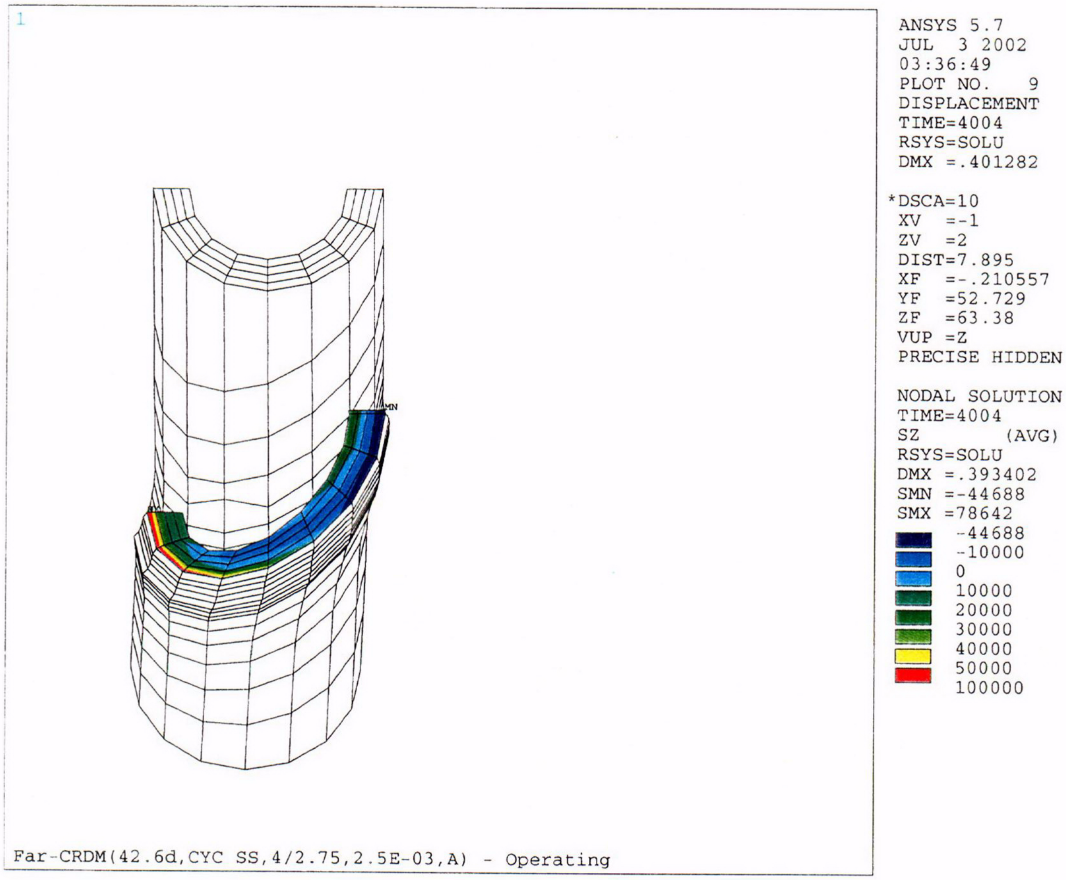


Figure 5-9 **Axial Stress Distribution at Steady State Conditions for the Outermost CRDM (42.6 Degrees) Penetration, Along a Plane Oriented Parallel to, and Just Above, the Attachment Weld**

6 FLAW TOLERANCE CHARTS

6.1 INTRODUCTION

The flaw tolerance charts were developed using the stress analysis of each of the penetration locations as discussed in Section 5. The crack growth law developed for Turkey Point Units 3&4 in Section 4.2 was used for each case, and several flaw tolerance charts were developed for each penetration location. The first series of charts characterizes the growth of a part through flaw, and the second series of charts characterizes the growth of a through-wall flaw in the length direction. The allowable safe operating life of the penetration nozzle may then be directly determined, using the combined results of the two charts. All times resulting from these calculations are effective full power years, since crack growth will only occur at operating temperatures.

6.2 OVERALL APPROACH

The results of the three-dimensional stress analysis of the penetration locations were used directly in the flaw tolerance evaluation.

The crack growth evaluation for the part-through flaws was based on the worst stress distribution through the penetration wall at the location of interest of the penetration. The highest stressed location was found to be in the immediate vicinity of the weld for both the center and outermost penetrations.

The stress profile was represented by a cubic polynomial:

$$\sigma(x) = A_0 + A_1 x + A_2 x^2 + A_3 x^3 \qquad (6\text{-}1)$$

where:

x = the coordinate distance into the nozzle wall
σ = stress perpendicular to the plane of the crack
A_I = coefficients of the cubic polynomial fit

For the surface flaw with length six times its depth, the stress intensity factor expression of Raju and Newman [5A] was used. The stress intensity factor $K_I(\Phi)$ can be calculated anywhere along the crack front. The point of maximum crack depth is represented by $\Phi = 0$, and this location was also found to be the point of maximum K_I for the cases considered here. The following expression is used for calculating $K_I(\Phi)$, where Φ is the angular location around the crack. The units of $K_I(\Phi)$ are ksi$\sqrt{in}$.

$$K_I(\Phi) = \left[\frac{\pi a}{Q}\right]^{0.5} \sum_{j=0}^{3} G_j\left(a/c,\ a/t,\ t/R,\ \Phi\right) A_j a^j \qquad (6\text{-}2)$$

The boundary correction factors G_0 (Φ), G_1 (Φ), G_2 (Φ) and G_3 (Φ) are obtained by the procedure outlined in reference [5A]. The dimension "a" is the crack depth, and "c" is the semi crack length, while "t" is the wall thickness. "R" is the inside radius of the tube, and "Q" is the shape factor.

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6.3 AXIAL FLAW PROPAGATION

CRDM Surface Flaws

The results of the calculated growth through the wall thickness of the CRDM penetration nozzles for surface flaws are shown in Figures 6-2 through 6-8 for inside surface flaws. For outside surface flaws the results are shown in Figures 6-9 and 6-10. Based on the discussion in MRP-55 report [4H], the use of stress intensity factors less than $15\,\text{MPa}\sqrt{\text{m}}$ involves assumption not currently substantiated by actual CGR data for CRDM nozzle materials. Therefore, these crack growth curves begin at a flaw depth that results in a stress intensity factor of $15\,\text{MPa}\sqrt{\text{m}}$, which exceeds the threshold value of $9\,\text{MPa}\sqrt{\text{m}}$. This may result in curves with different initial flaw sizes, as seen for example in Figure 6-3. Note that results are only provided for the uphill and downhill sides of each penetration nozzle; the stresses for the regions 90 degrees from these locations are compressive. If flaws are found in such a location, the results for either the uphill or downhill location, whichever is closer, can be used.

Each of these figures allows the future allowable service time to be estimated graphically, as discussed in Section 3. Results are shown for each of the penetration nozzles analyzed in each of these figures. The stresses are much higher near the attachment weld than at 0.5 inch below or above it, so separate figures have been provided for these three regions. Also, the stresses are different on the downhill side of the penetration as opposed to the uphill side, so these two cross sections have also been treated separately.

A set of guidelines for evaluating an indication found during inspection has been provided in Appendix B. Example problems following the previously mentioned guidelines have also been provided in Appendix C for a range of possible flaw types.

CRDM Through-Wall Flaws

The projected crack growth of a through-wall flaw in the CRDM penetration nozzles are the primary concern in evaluating the structural integrity of head penetrations. In some cases, the through-wall flaw may be located sufficiently below the attachment weld that additional time may be required for the flaw to grow to the attachment weld. To provide a means to evaluate the duration of this additional time, a series of flaw tolerance charts for through-wall flaws were prepared.

Charts were prepared for each of the penetrations evaluated, for both the uphill and downhill locations, as shown in Figures 6-12 through 6-20. In each figure, the through-wall crack length is measured from the bottom of the nozzle. Note that in all the cases, the crack slows down significantly as it grows above the weld, due to the decreasing magnitude of the stress field. This provides further assurance that axial flaws will not extend to a critical length which exceeds 15 inches, regardless of the duration of crack growth.

Head Vent

The only flaw tolerance chart that is necessary for the head vent region is for flaws at and above the weld, since there is no portion of the head vent which projects below the weld. Figure 6-8 provides the projected growth of a part through flaw in the head vent just above the attachment weld. The growth through the wall is relatively rapid, because the thickness of the head vent is small.

6.4 CIRCUMFERENTIAL FLAW PROPAGATION

Since circumferentially oriented flaws have been found at five plants (Bugey 3, Oconee 2, Crystal River 3, Davis Besse, and Oconee 3), it is important to consider the possibility of crack extension in the circumferential direction. The first case was discovered as part of the destructive examination of the tube with the most extensive circumferential cracking at Bugey 3. The crack was found to have extended to a depth of 2.25 mm in a wall thickness of 16 mm. The flaw was found at the outside surface of the penetration (number 54) at the downhill side location, just above the weld.

The circumferential flaws in Oconee Unit 3 were discovered during the process of repairing a number of axial flaws, whereas the circumferential flaw in Oconee Unit 2 and Crystal River Unit 3 were discovered by UT. Experience gained from these findings has enabled the development of UT procedures capable of detecting circumferential flaws reliably.

To investigate this issue completely, a series of crack growth calculations were carried out for a postulated surface circumferential flaw located just above the head penetration weld, in a plane parallel to the weld itself. This is the only flaw plane that could result in a complete separation of the penetration nozzle, since all others would result in propagation below the weld, and therefore there is no chance of complete separation because the remaining weld would hold the penetration nozzle in place.

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]a,c,e The results of this calculation are shown in Figure 6-21. From Figure 6-21, it can be seen that the time required for propagation of a circumferential flaw to a point where the integrity of the CRDM penetration nozzle would be affected (330 degrees [10]) would be about 24 years. Due to the conservatism in the calculations (the time period for a surface flaw to become a through-wall flaw was ignored) the service life is likely to be even longer. In addition, due to uncertainties in the exact composition of the chemical environment in contact with the nozzle OD, a multiplicative factor of 2.0 is used in the CGR for all circumferential surface flaws on the OD of the head penetration nozzles located above the elevation of the J-groove weld.

6.5 FLAW ACCEPTANCE CRITERIA

Now that the projected crack growth curves have been developed, the question remains as to what flaw size would be acceptable for further service.

Acceptance criteria have been developed for indications found during inspection of reactor vessel upper head penetration as part of an industry program coordinated by NEI (formerly NUMARC). Such criteria are normally found in Section XI of the ASME Code, but Section XI does not require in-service inspection of these regions and therefore acceptance criteria are not available. In developing the enclosed acceptance criteria, the approach used was very similar to that used by Section XI, in that an industry consensus was reached using input from both operating utility technical staff and each of the three PWR vendors. The criteria developed are applicable to all PWR plant designs.

Since the discovery of the leaks at Oconee and ANO-1, the acceptance criteria have been revised slightly to cover flaws on the outside diameter of the penetration below the attachment weld, and flaws in the attachment weld. These revised criteria are now in draft form, but they are expected to be acceptable to the NRC, and will be used in these evaluations. The draft portions of the acceptance criteria will be noted below.

The criteria presented herein are limits on flaw sizes, which are acceptable. The criteria are to be applied to inspection results. It should be noted that determination of the future service during which the criteria are satisfied is plant-specific and dependent on flaw geometry and loading conditions.

It has been previously demonstrated by each of the owners groups that the penetration nozzles are very tolerant of flaws and there is only a small likelihood of flaw extensions to larger sizes. Therefore, it was concluded that complete fracture of the penetration nozzle is highly unlikely. The approach used here is more conservative than that used in Section XI applications where the acceptable flaw size is calculated by placing a margin on the critical flaw size. For the current application, the critical flaw size would be far too large to allow a practical application of the approach used in Section XI applications, so protection against leakage is the priority.

The acceptance criteria presented herein apply to all the flaw types regardless of orientation and shape. Similar to the approach used in Section XI, flaws are first characterized according to established rules and then compared with acceptance criteria.

Flaw Characterization

Flaws detected must be characterized by the flaw length and preferably flaw depth. The proximity rules of Section XI for considering flaws as separate, may be used directly (Section XI, Figure IWA 3400-1). This figure is reproduced here as Figure 6-22.

When a flaw is detected, its projections in both the axial and circumferential directions must be determined. Note that the axial direction is always the same for each penetration, but the circumferential direction will be different depending on the angle of intersection of the penetration nozzle with the vessel head. The "circumferential" direction of interest here is along the top of the attachment weld, as illustrated in Figure 6-23. It is this angle which will change for each penetration nozzle and the top of the attachment weld is also the plane which could cause separation of the penetration nozzle from the vessel head. The location of the flaw relative to both the top and bottom of the partial penetration attachment weld must also be determined since a potential leak path exists when a flaw propagates through the penetration nozzle wall and up the penetration nozzle past the attachment weld. Schematic of a typical weld geometry is shown in Figure 6-24.

Flaw Acceptance Criteria

The maximum allowable depth (a_f) for axial flaws on the inside surface of the penetration nozzle, at or above the weld is 75 percent of the penetration wall thickness. The term a_f is defined as the maximum size to which the detected flaw is calculated to grow in a specified time period. This 75 percent limitation was selected to be consistent with the maximum acceptable flaw depth in Section XI and to provide an additional margin against through wall penetration. There is no concern about separation of the penetration nozzle from the vessel head, unless the flaw is above the attachment weld and oriented circumferentially. Calculations have been completed to show that the geometry of all penetrations can support a continuous circumferential flaw with a depth of 75 percent of the wall thickness.

Axial inside surface flaws found below the weld are acceptable regardless of depth as long as their upper extremity does not reach the bottom of the weld during the period of service until the next inspection. Axial flaws that extend above the weld are limited to 75 percent of the wall thickness.

Axial flaws on the outside surface of the penetration nozzle below the attachment weld are acceptable regardless of depth, as long as they do not extend into the attachment weld during the period of service until next inspection. Outside surface flaws above the attachment weld must be evaluated on a case by case basis, and must be discussed with the regulatory authority.

Circumferential flaws located below the weld are acceptable regardless of their depth, provided the length is less than 75 percent of the penetration nozzle circumference for the period of service until the next inspection. Circumferential flaws detected in this area have no structural significance except that loose parts must be avoided. To this end, intersecting axial and circumferential flaws shall be removed or repaired. Circumferential flaws at and above the weld must be discussed with the regulatory authority on a case by case basis.

Surface flaws located in the attachment welds themselves are not acceptable regardless of their depth. This is because the crack growth rate is several times faster than that of the Alloy 600 material, and also because depth sizing capability does not yet exist for indications in the attachment weld.

The flaw acceptance criteria are summarized in Table 6-1. Flaws that exceed these criteria must be repaired unless analytically justified for further service. These criteria have been reviewed and approved by the NRC, as documented in references [7, 8] with the exception of the draft criteria discussed above, for outside surface flaws and flaws in the attachment weld. These criteria are identical with the draft acceptance criteria now being considered for Section XI, for head penetrations.

It is expected that the use of these criteria and crack growth curves will provide conservative predictions of the allowable service time.

Table 6-1 Summary of R.V. Head Penetration Flaw Acceptance Criteria (Limits for Future Growth)				
	Axial		Circumferential	
Location	a_f	ℓ	a_f	ℓ
Below Weld (ID)	t	no limit	t	.75 circ.
At and Above Weld (ID)	0.75 t	no limit	*	*
Below Weld (OD)	t	no limit	t	.75 circ.
Above Weld (OD)	*	*	*	*

Note: Surface flaws of any size in the attachment weld are not acceptable.

* Requires case-by-case evaluation and discussion with regulatory authority.

a_f = Flaw Depth
ℓ = Flaw Length
t = Wall Thickness

Table 6-2 Turkey Point Units 3&4 Penetration Geometries [11A, 11B, 11C]		
Penetration Type	Wall Thickness (in.)	Penetration OD (in.)
CRDM	0.625	4.00
Head Vent	0.122	1.014

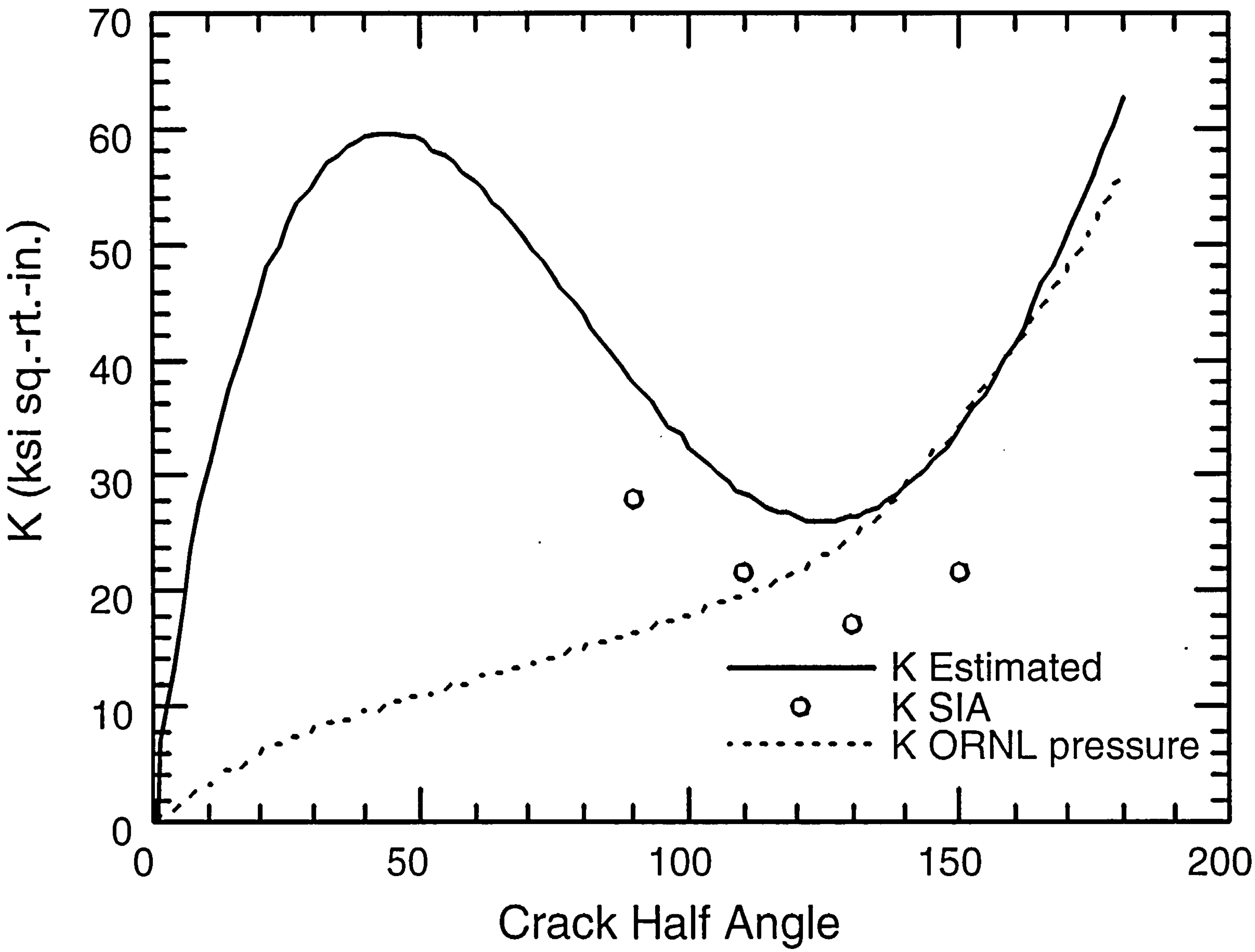

Figure 6-1 Stress Intensity Factor for a Through-Wall Circumferential Flaw in a Head Penetration

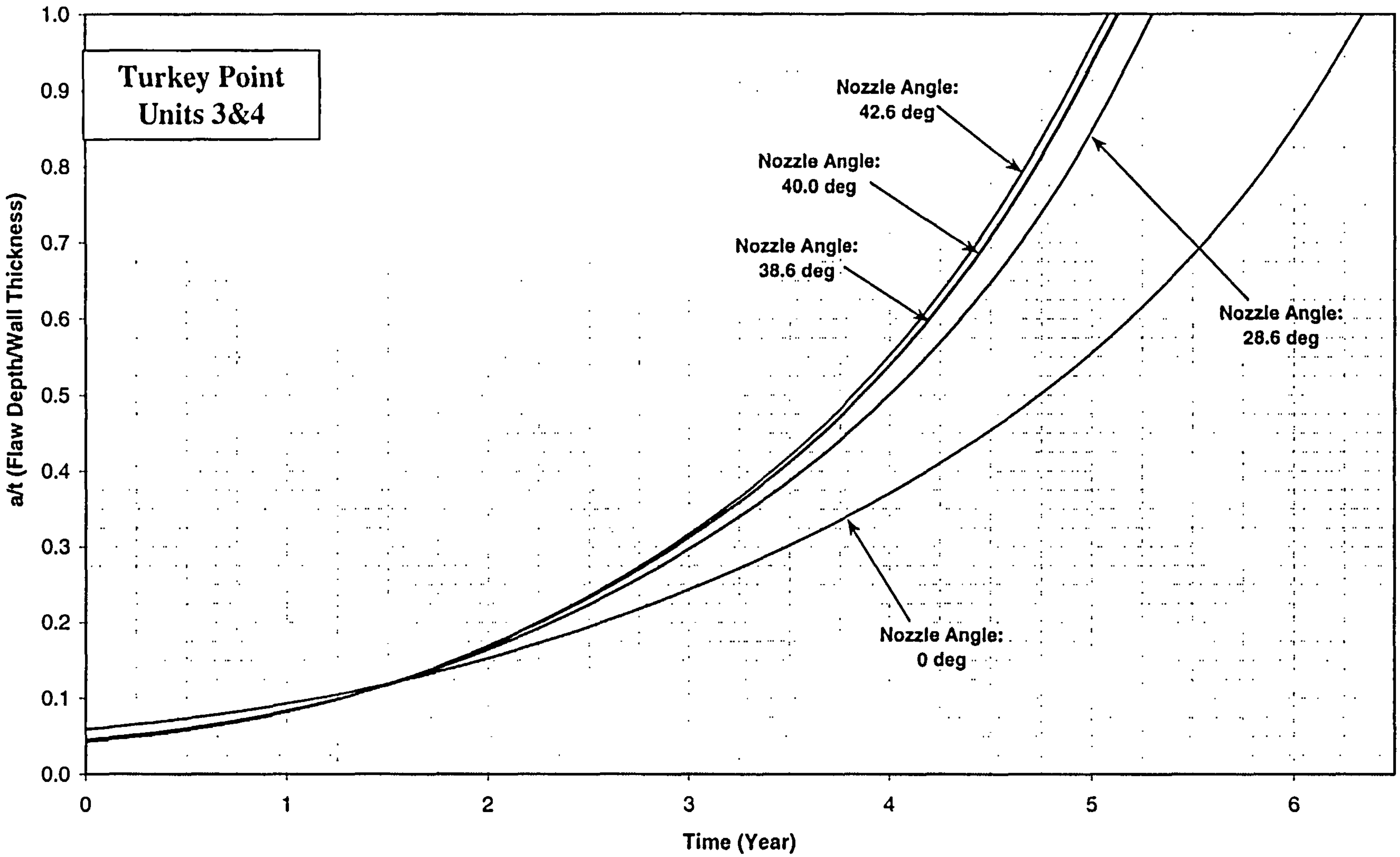

Figure 6-2 Inside, Axial Surface Flaws, .5" Below the Attachment Weld, Nozzle Uphill Side - Crack Growth Predictions (Note: All time (year) indicated in charts are in effective full power years)

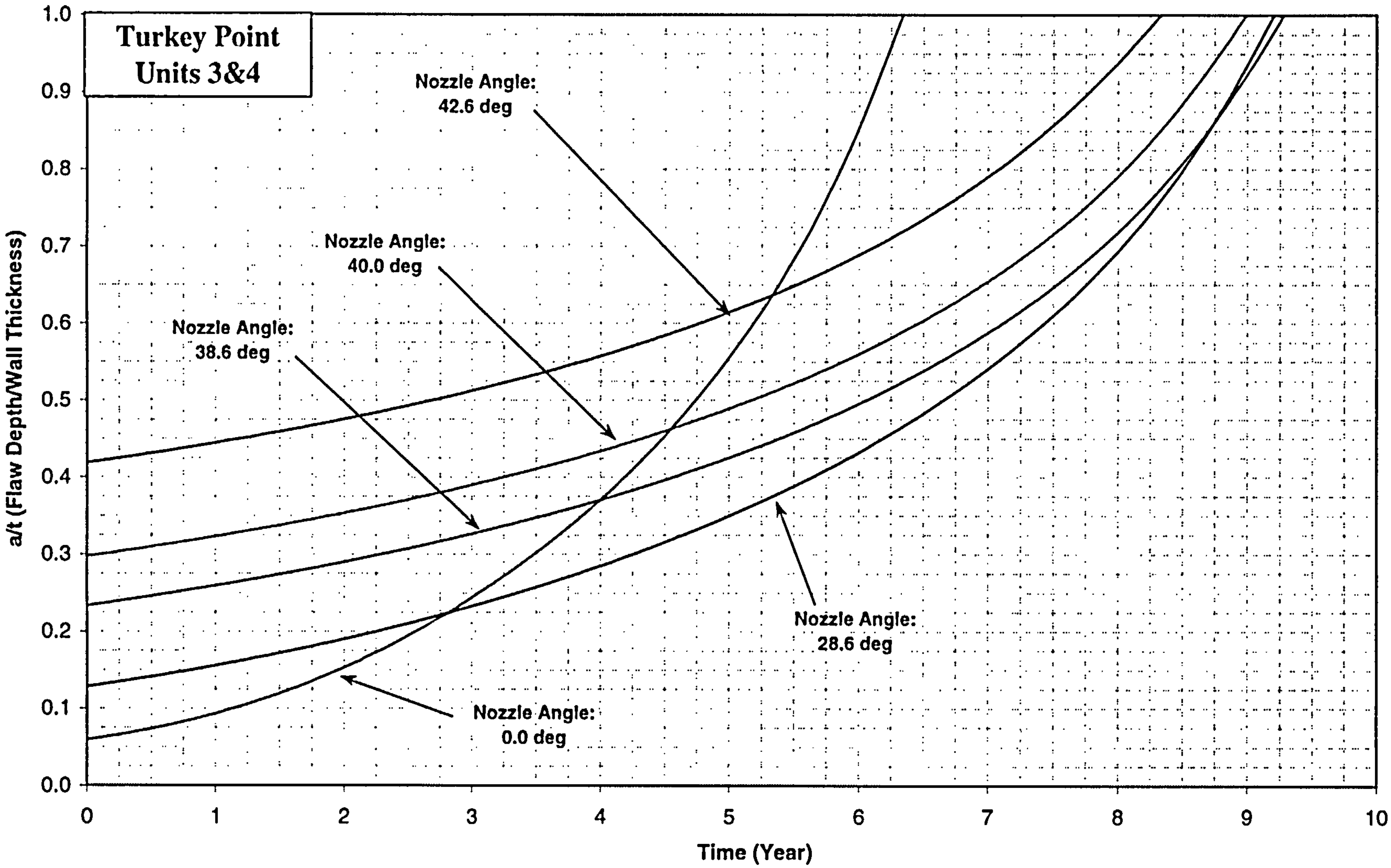

Figure 6-3 Inside, Axial Surface Flaws, .5" Below the Attachment Weld, Nozzle Downhill Side - Crack Growth Predictions

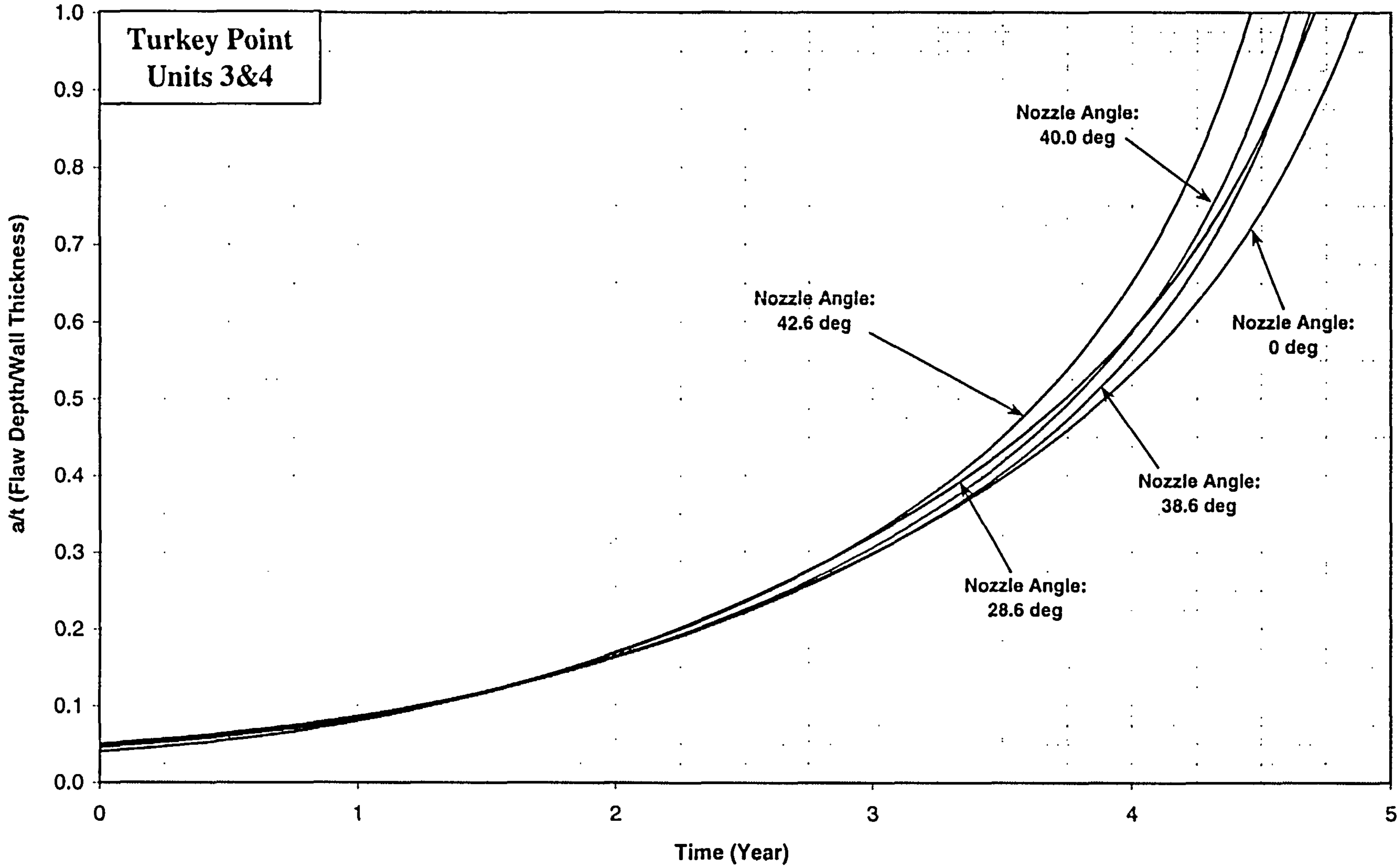

Figure 6-4 Inside, Axial Surface Flaws, At the Attachment Weld, Nozzle Uphill Side - Crack Growth Predictions

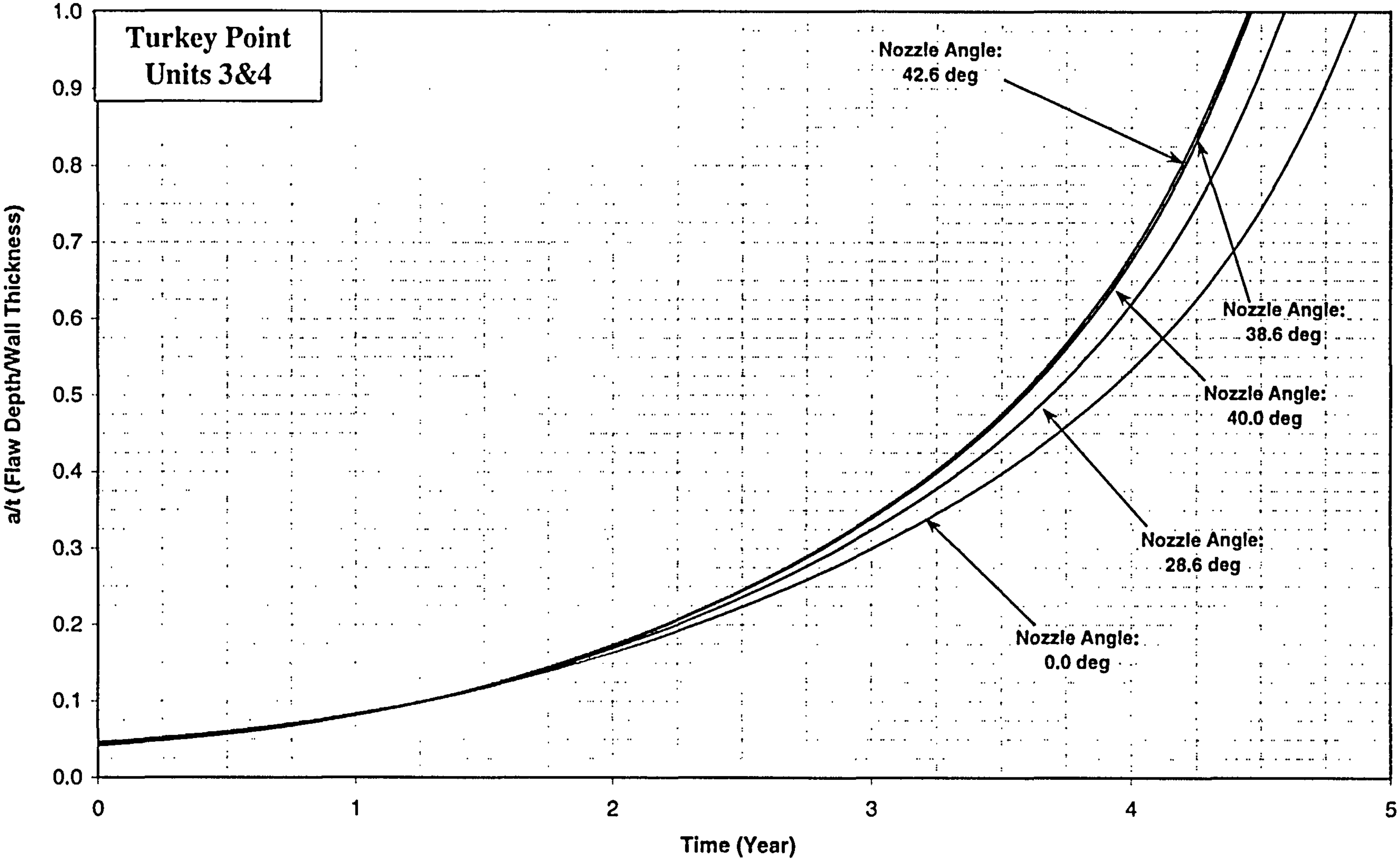

Figure 6-5 Inside, Axial Surface Flaws, At the Attachment Weld, Nozzle Downhill Side - Crack Growth Predictions

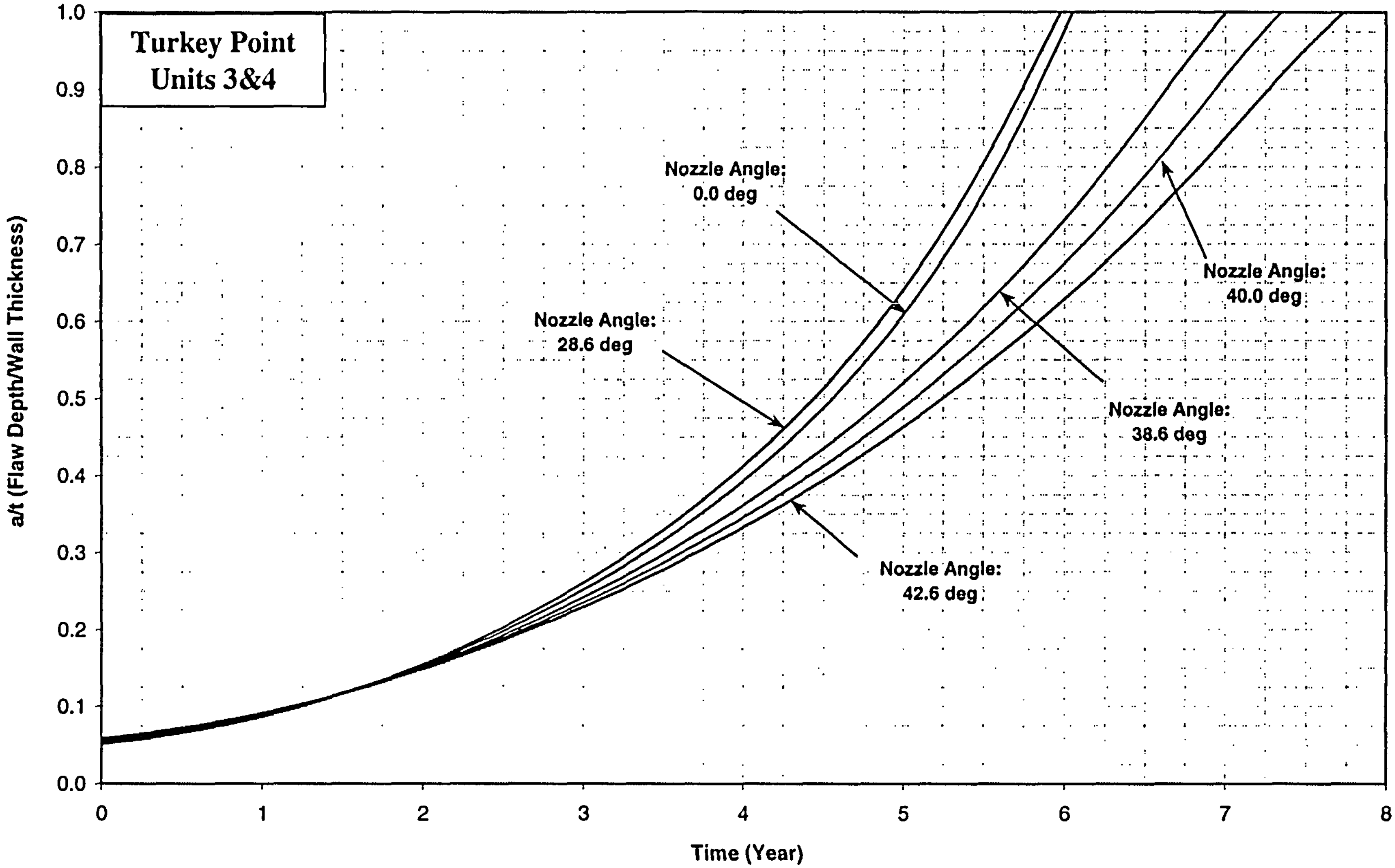

Figure 6-6 Inside, Axial Surface Flaws, .5" Above the Attachment Weld, Nozzle Uphill Side - Crack Growth Predictions

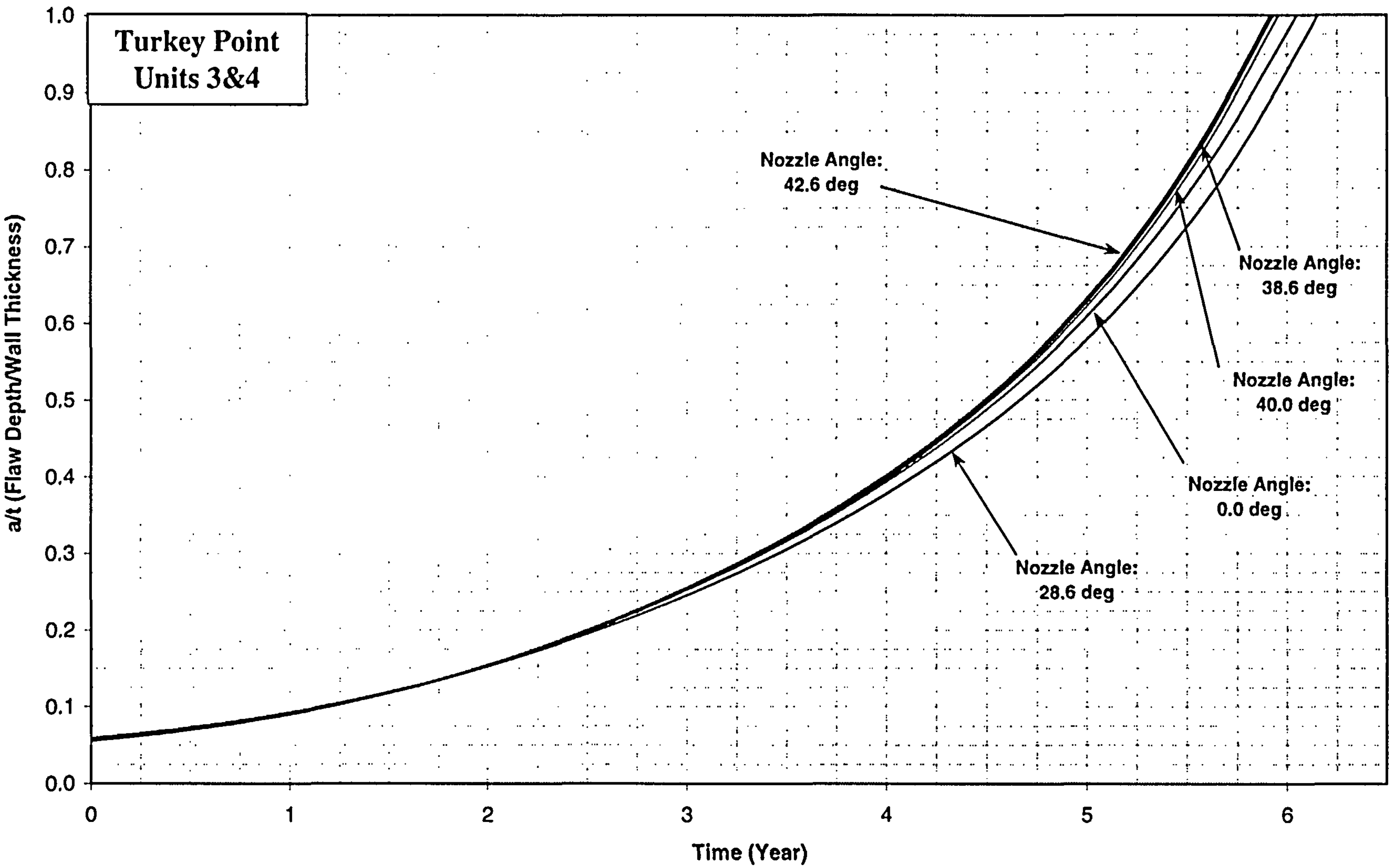

Figure 6-7 Inside, Axial Surface Flaws, .5" Above the Attachment Weld, Nozzle Downhill Side - Crack Growth Predictions

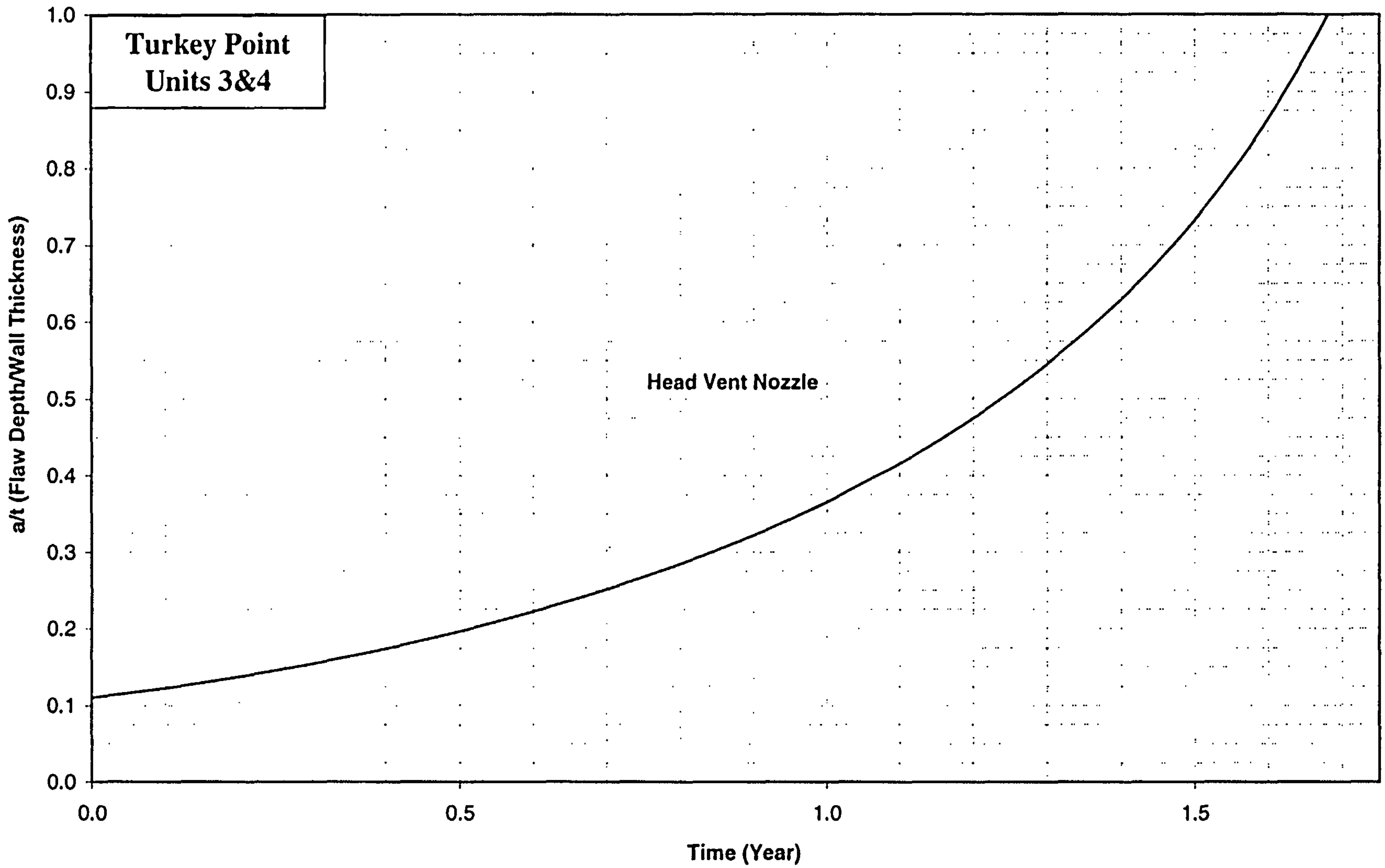

Figure 6-8 Inside, Axial Surface Flaws, At the Attachment Weld, Head Vent, Nozzle Downhill Side - Crack Growth Predictions

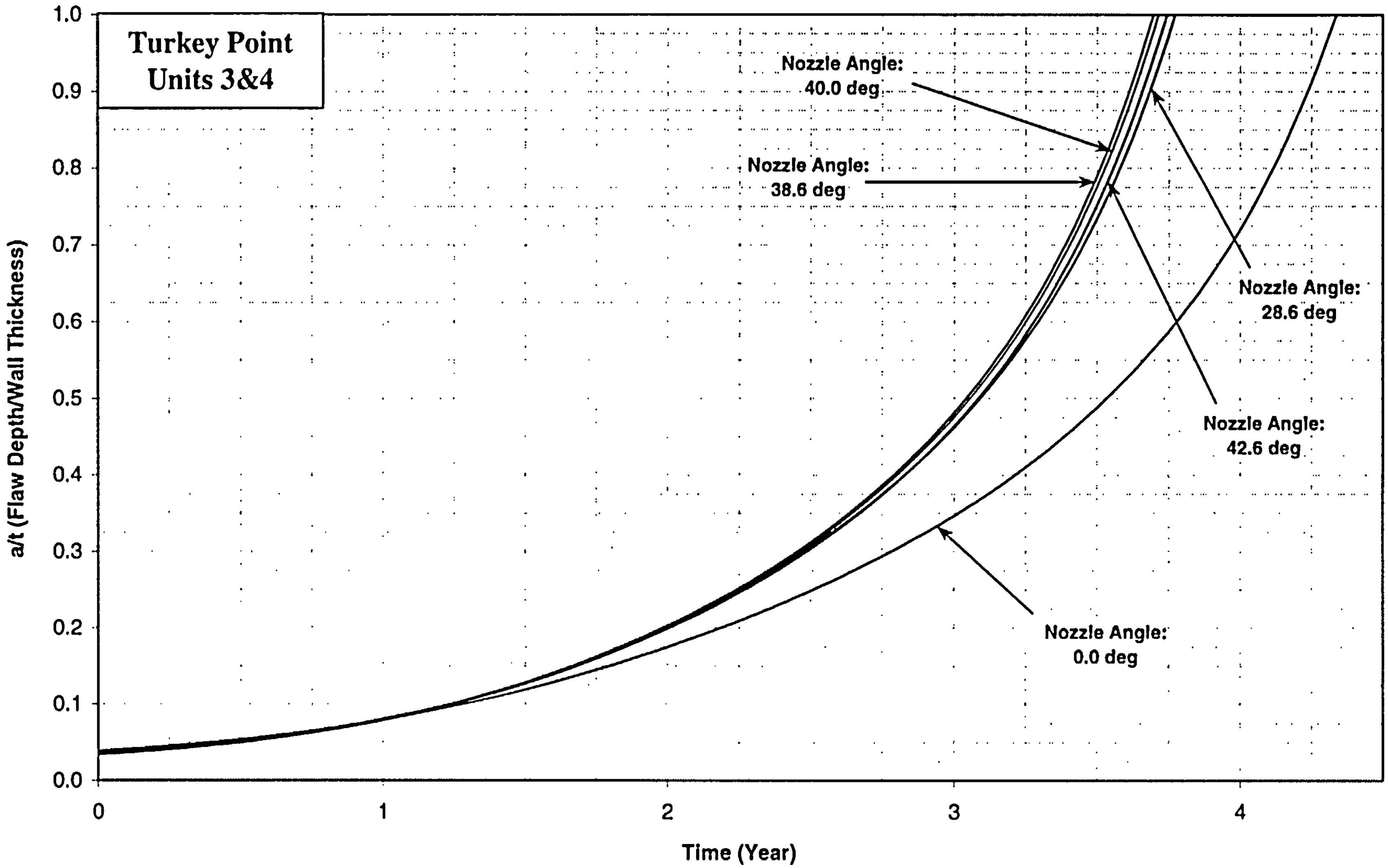

Figure 6-9 Outside, Axial Surface Flaws, Below the Attachment Weld, Nozzle Uphill Side - Crack Growth Predictions

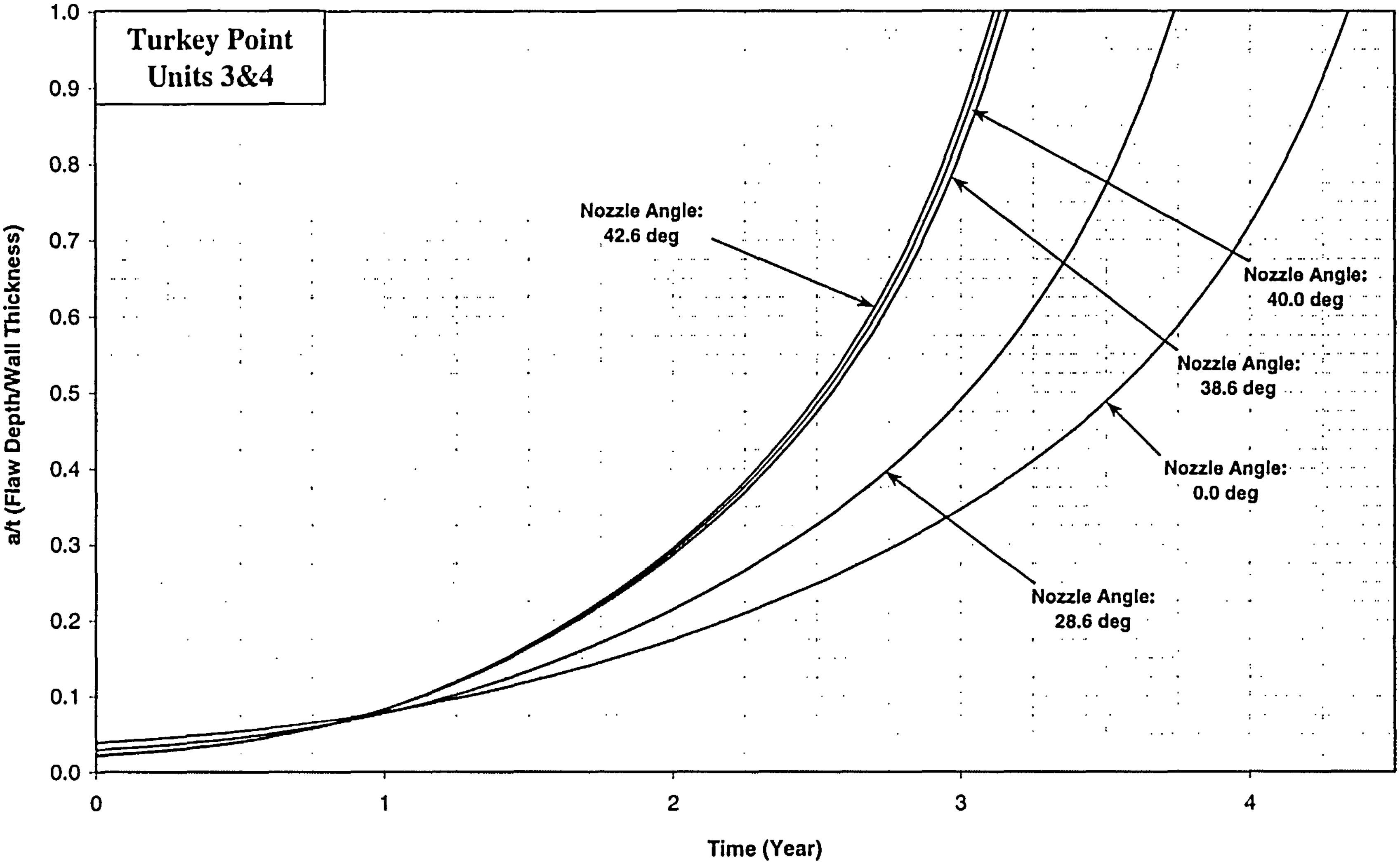

Figure 6-10 Outside, Axial Surface Flaws, Below the Attachment Weld, Nozzle Downhill Side - Crack Growth Predictions

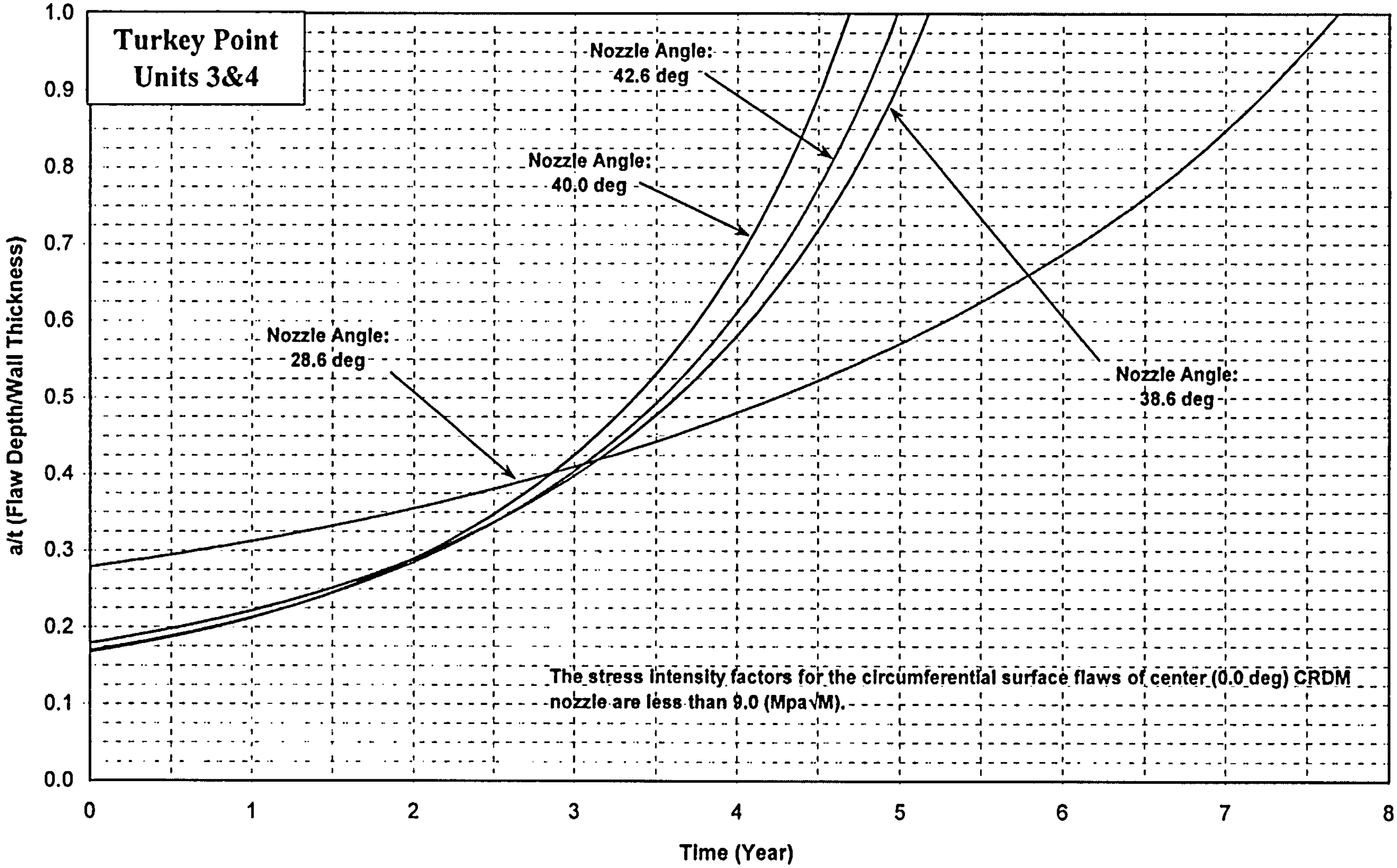

Figure 6-11 Outside, Circumferential Surface Flaws, Along the Top of the Attachment Weld - Crack Growth Predictions (MRP Factor of 2.0 Included)

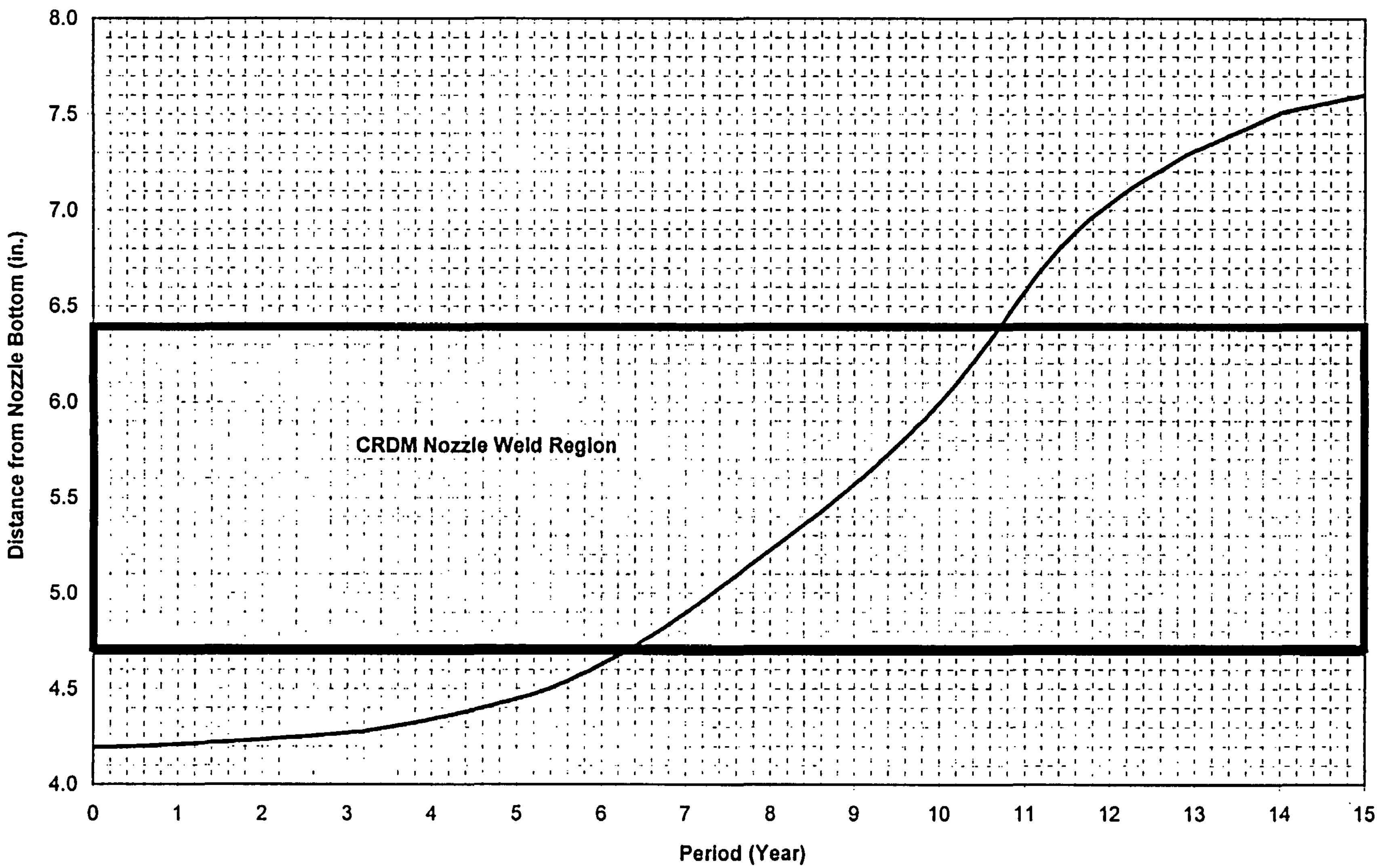

Figure 6-12 Through-Wall Axial Flaws Located in the Center CRDM (0.0 Degrees) Penetration, Uphill and Downhill Side - Crack Growth Predictions

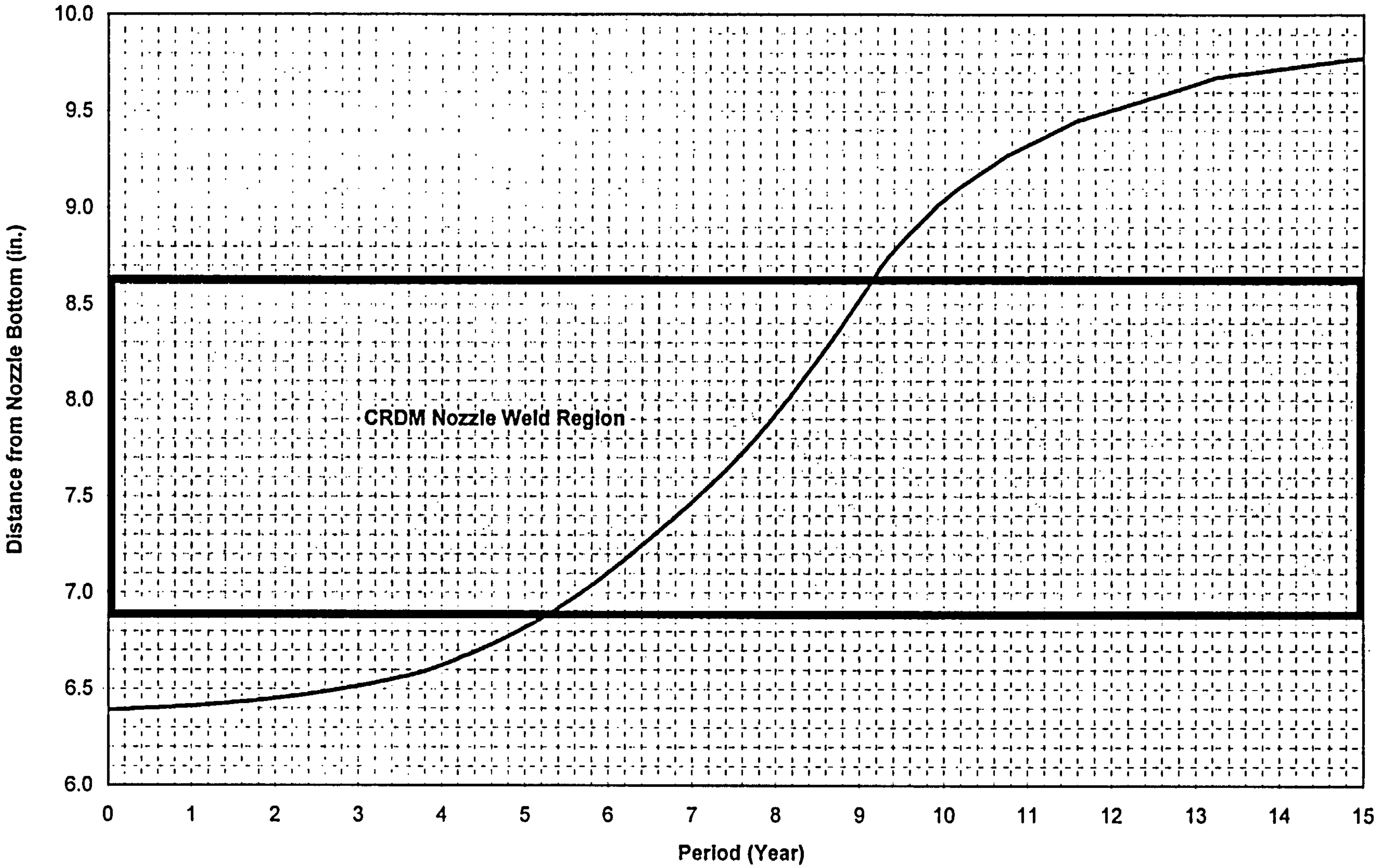

Figure 6-13 Through-Wall Axial Flaws Located in the 28.6 Degree Row of Penetrations, Uphill Side - Crack Growth Predictions

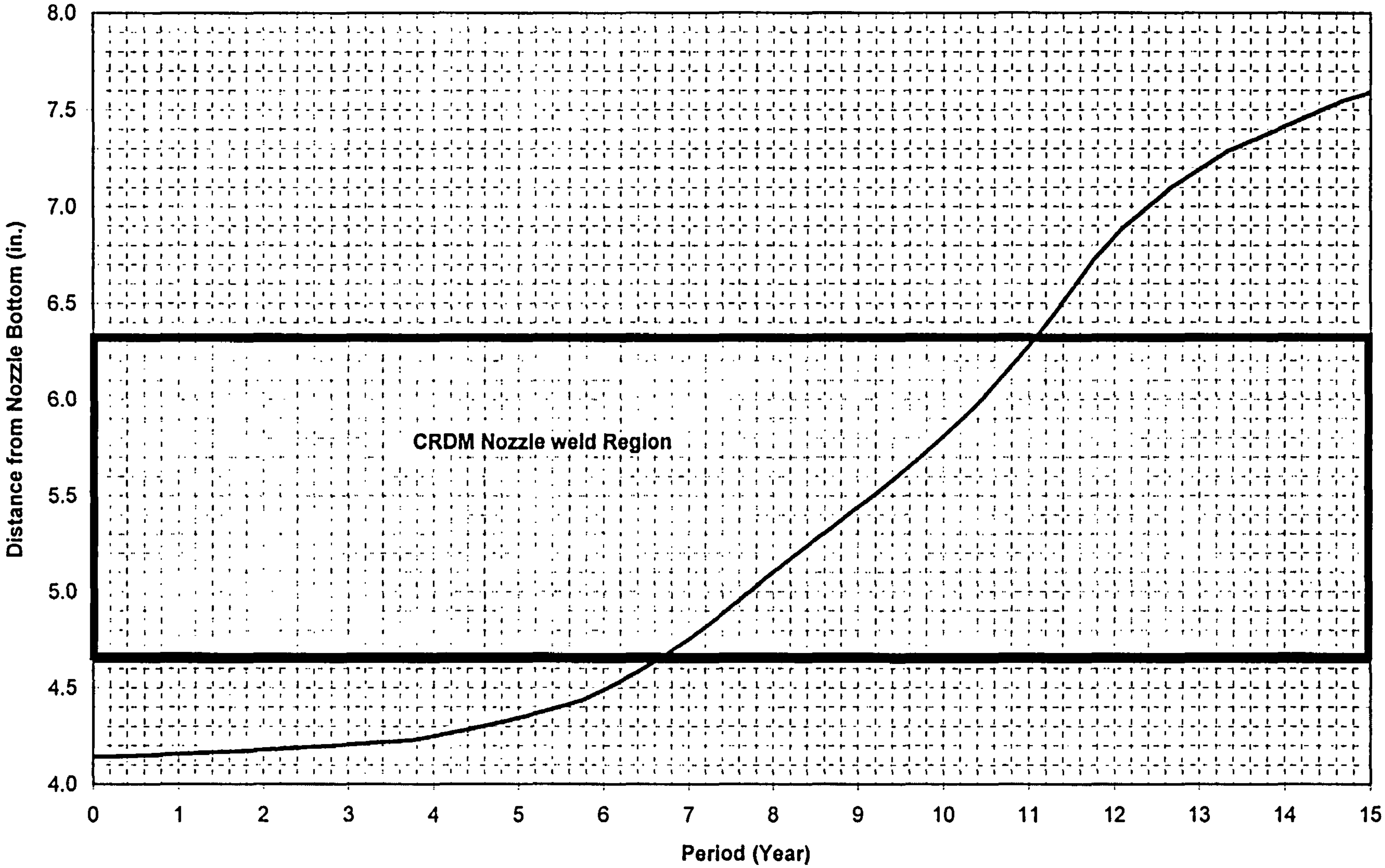

Figure 6-14 Through-Wall Axial Flaws Located in the 28.6 Degree Row of Penetrations, Downhill Side - Crack Growth Predictions

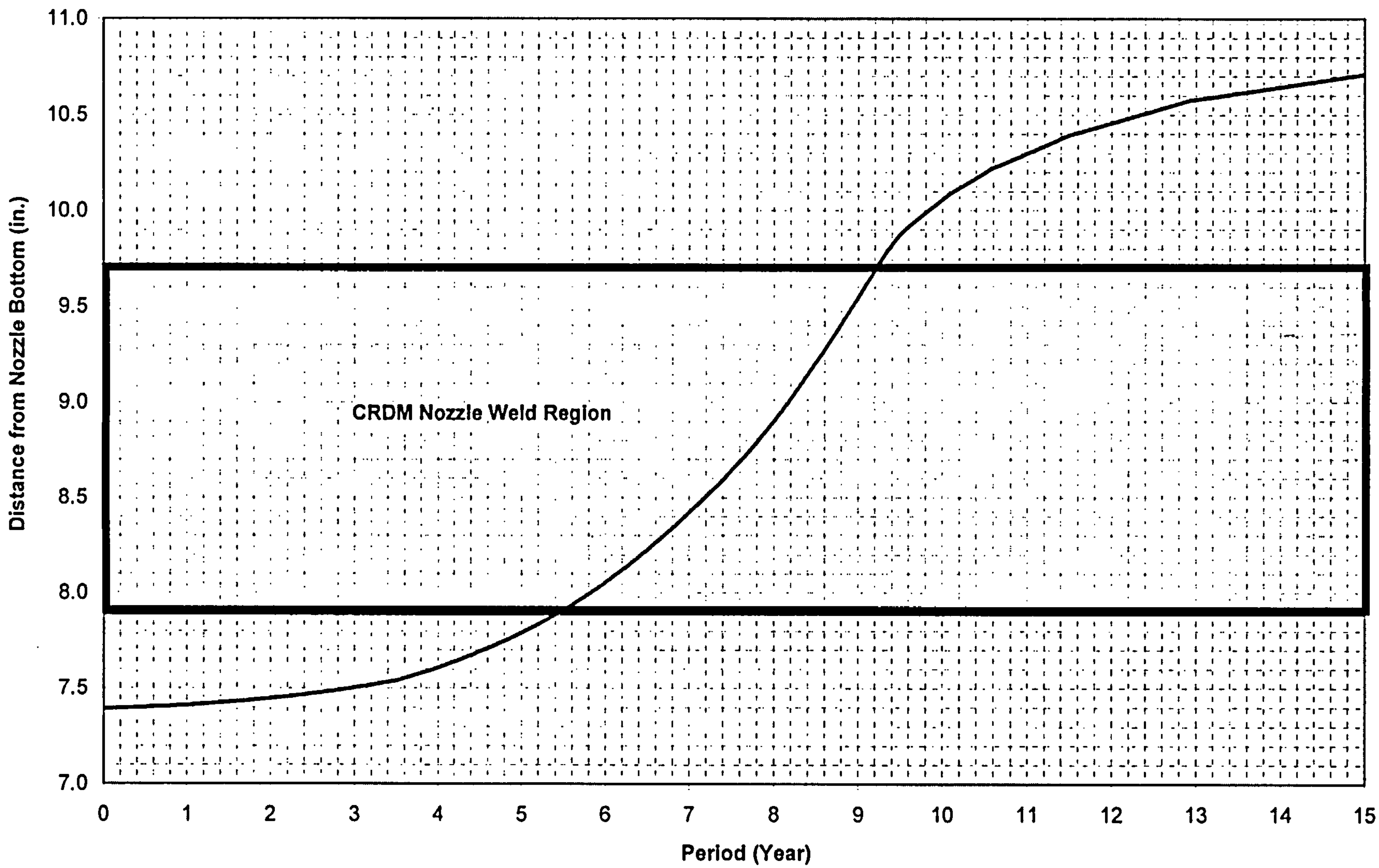

Figure 6-15 Through-Wall Axial Flaws Located in the 38.6 Degree Row of Penetrations, Uphill Side - Crack Growth Predictions

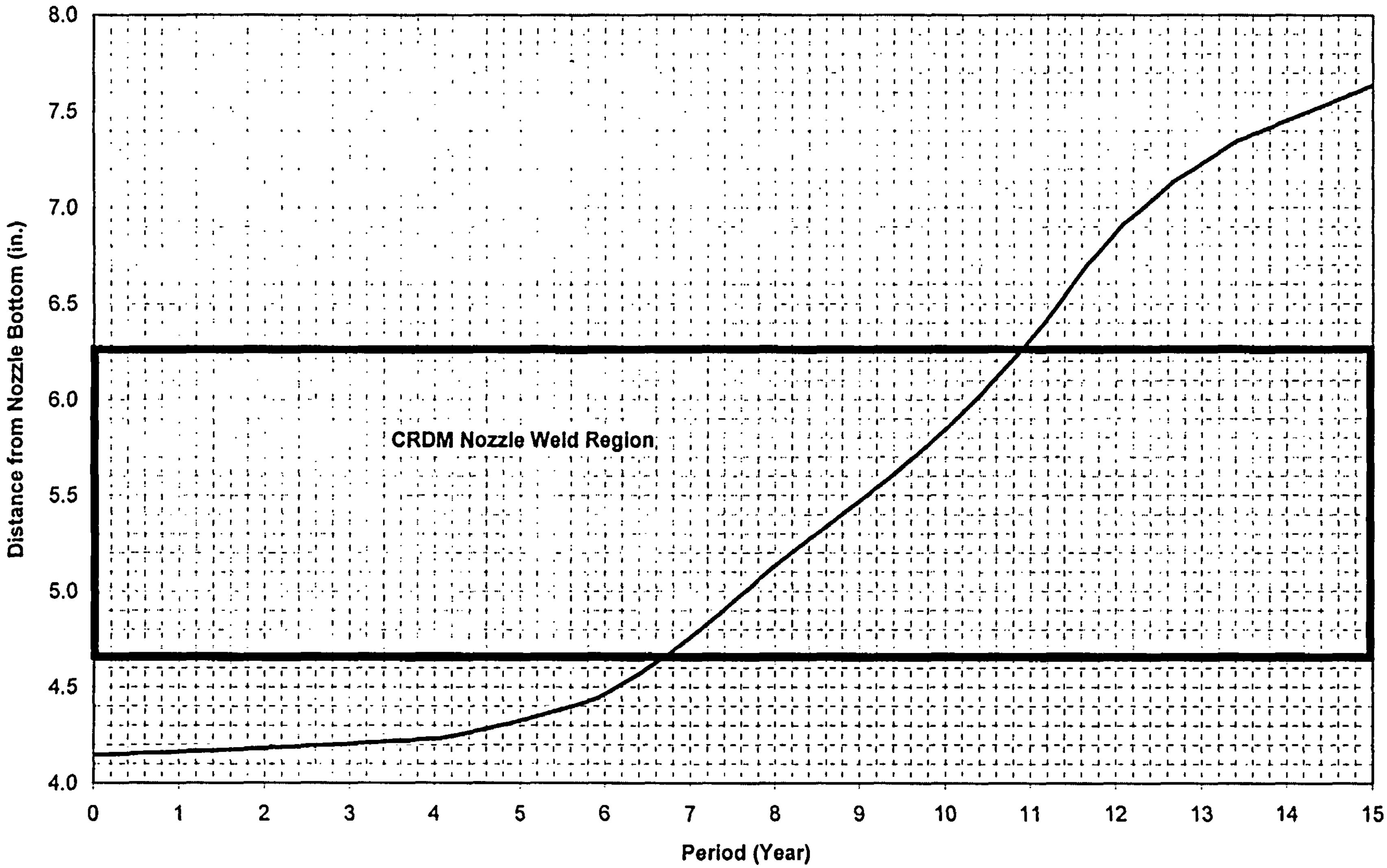

Figure 6-16 Through-Wall Axial Flaws Located in the 38.6 Degree Row of Penetrations, Downhill Side - Crack Growth Predictions

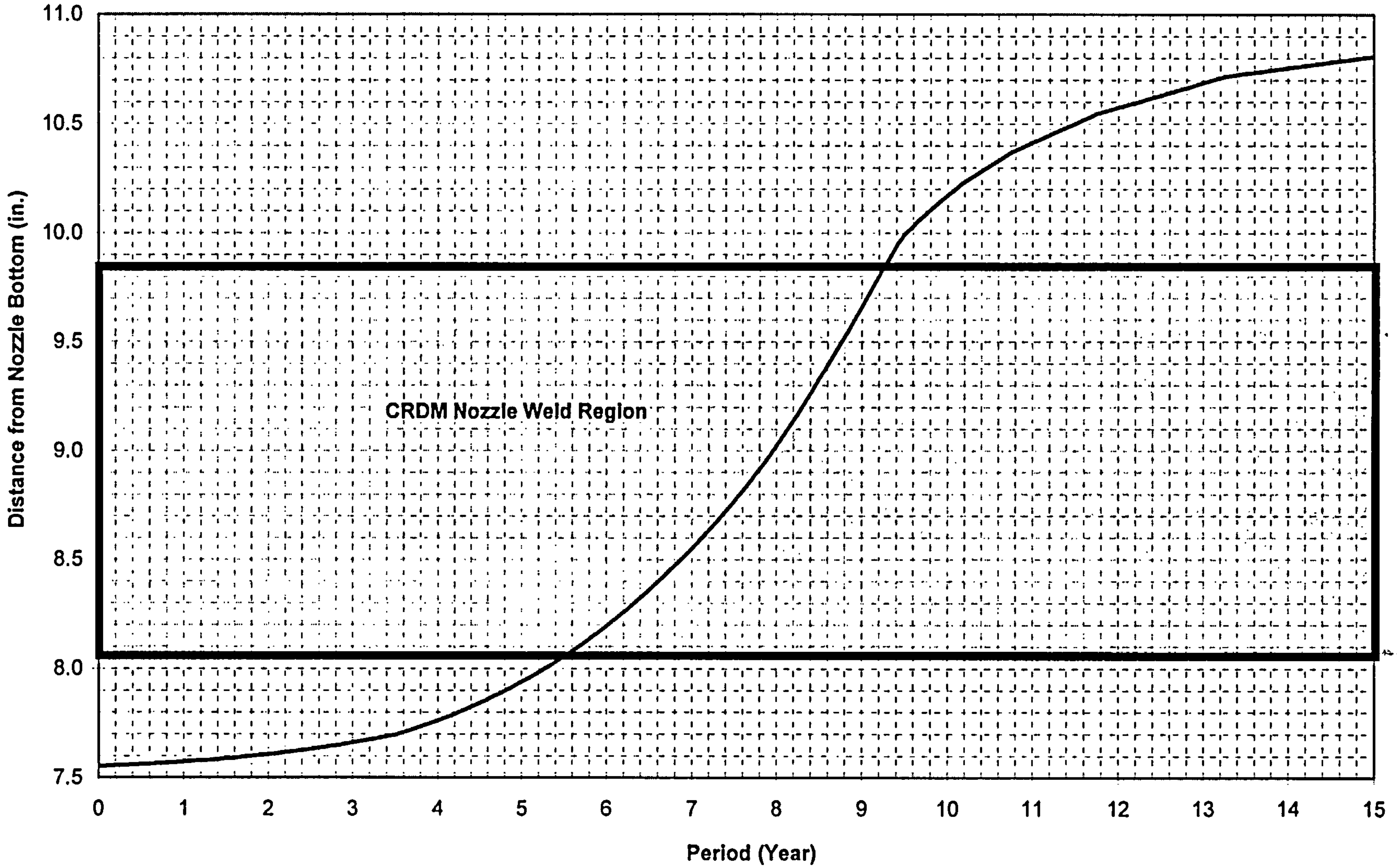

Figure 6-17 Through-Wall Axial Flaws Located in the 40.0 Degree Row of Penetrations, Uphill Side - Crack Growth Predictions

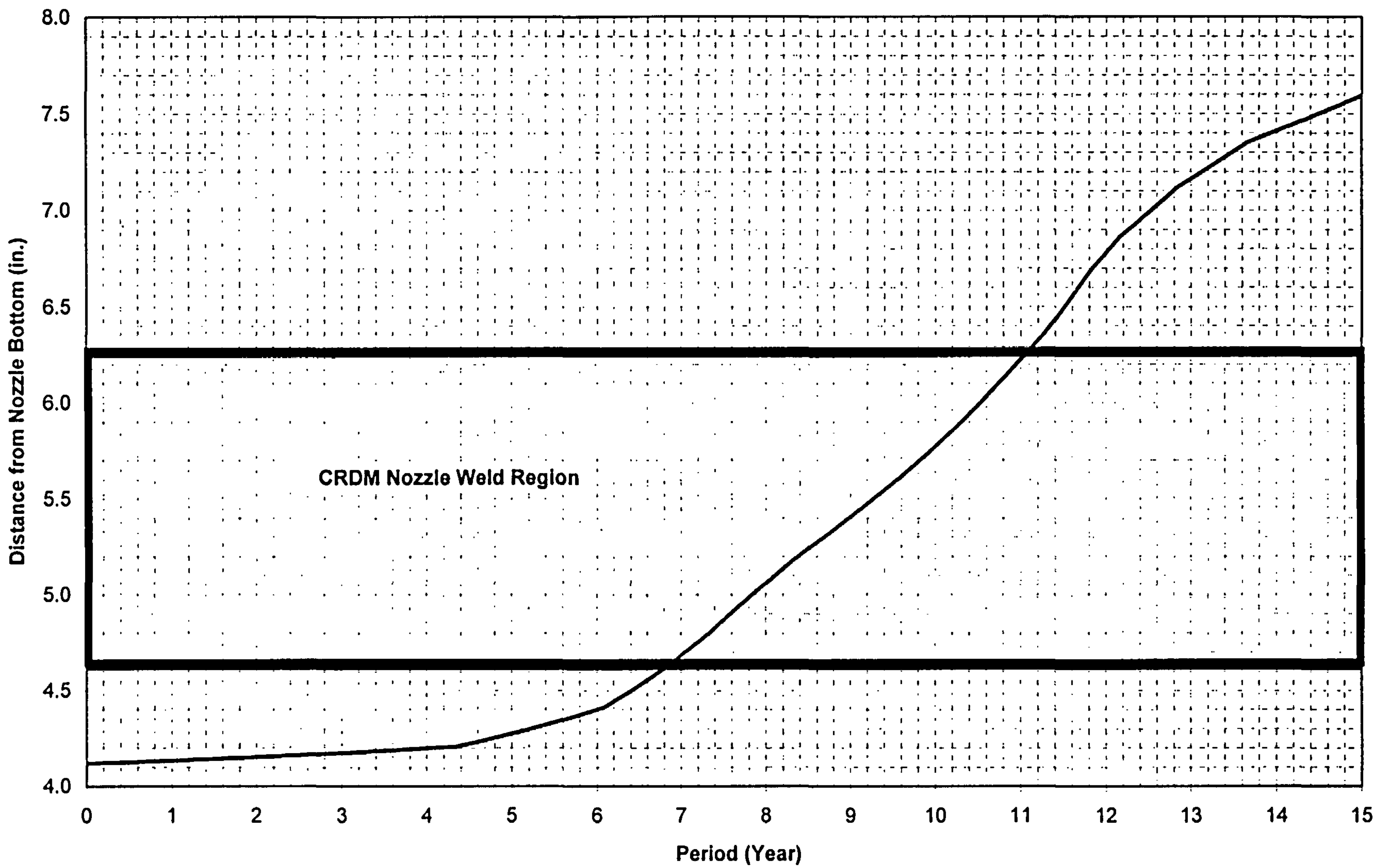

Figure 6-18 Through-Wall Axial Flaws Located in the 40.0 Degree Row of Penetrations, Downhill Side - Crack Growth Predictions

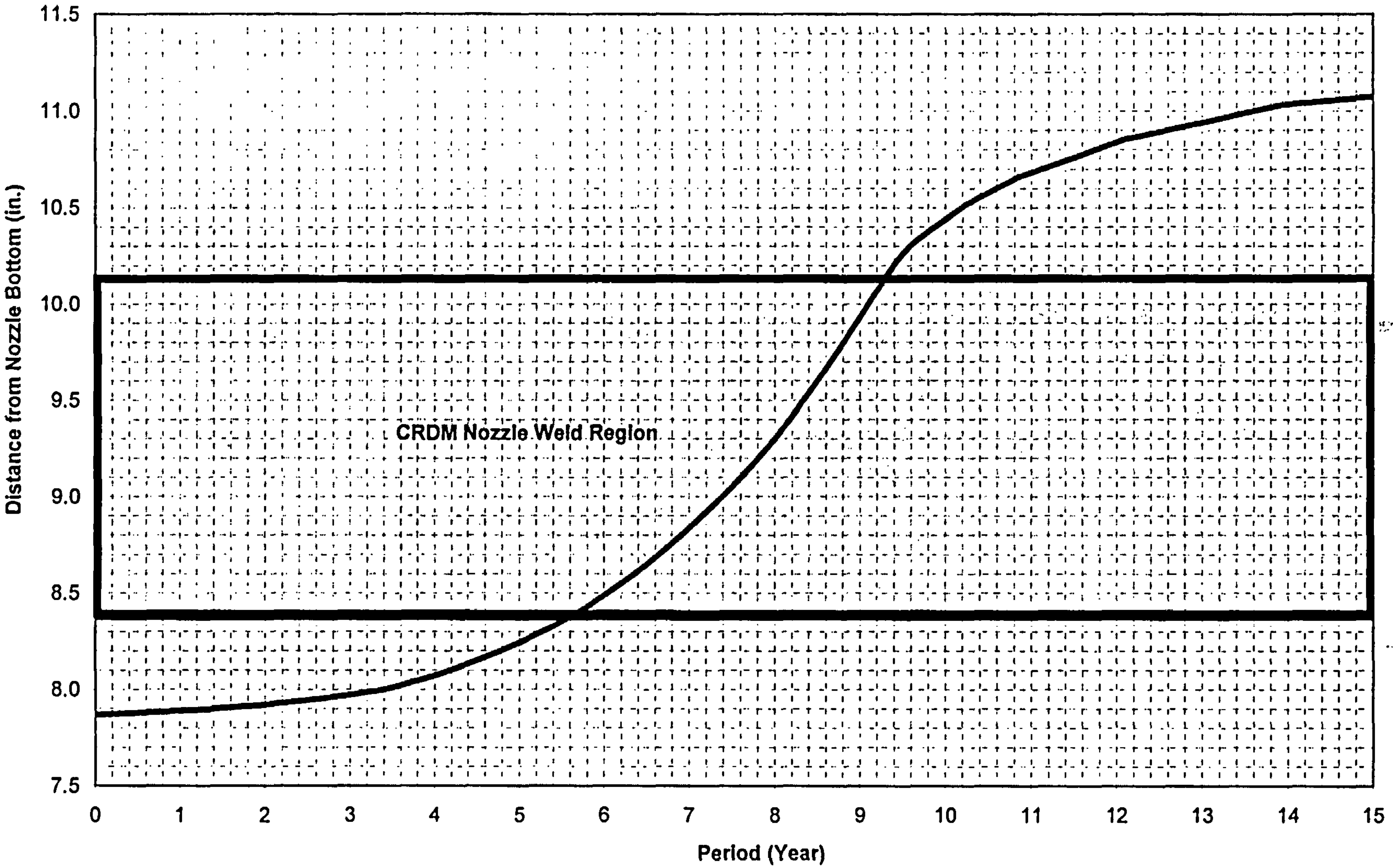

Figure 6-19 Through-Wall Axial Flaws Located in the 42.6 Degree Row of Penetrations, Uphill Side - Crack Growth Predictions

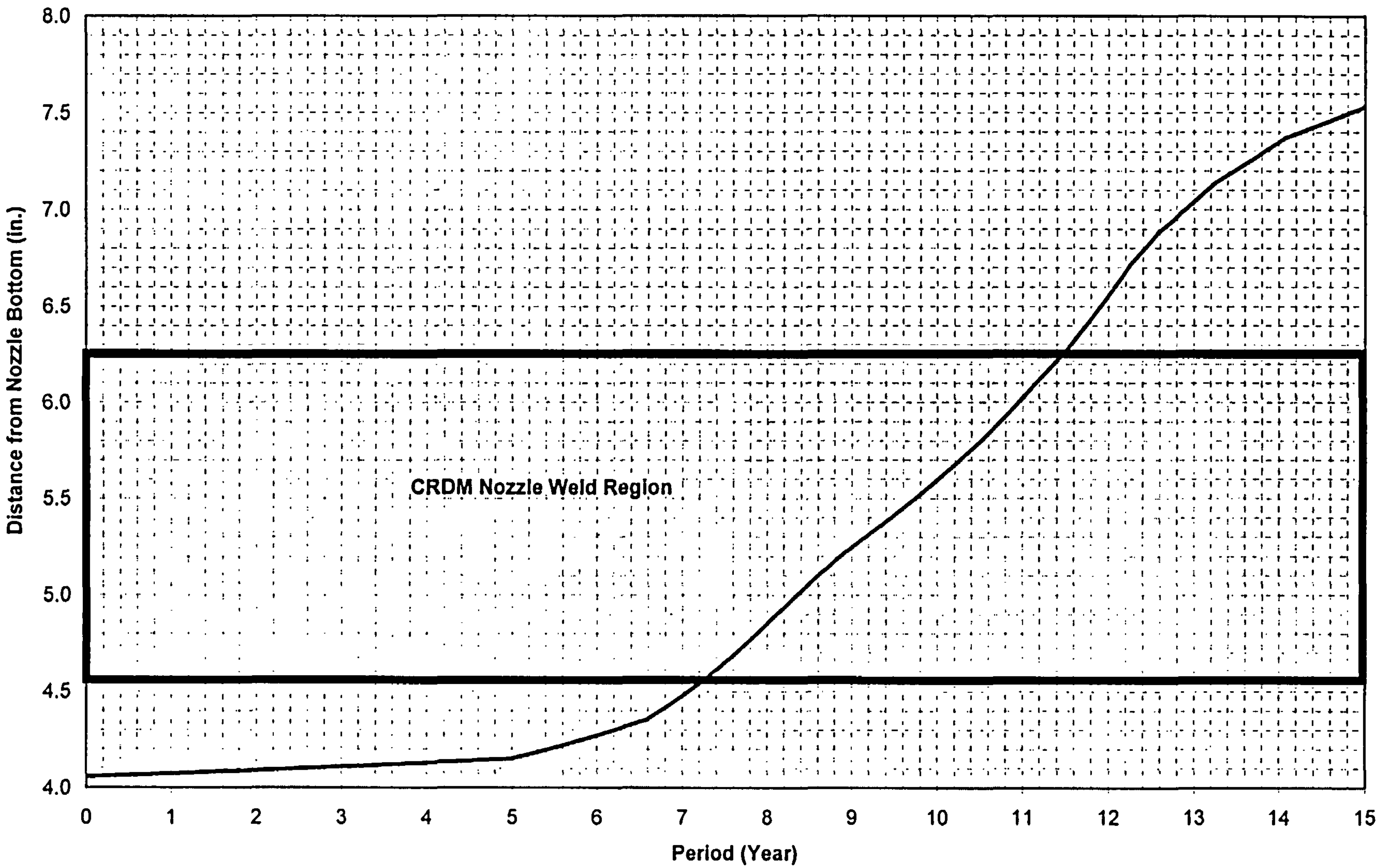

Figure 6-20 Through-Wall Axial Flaws Located in the 42.6 Degree Row of Penetrations, Downhill Side - Crack Growth Predictions

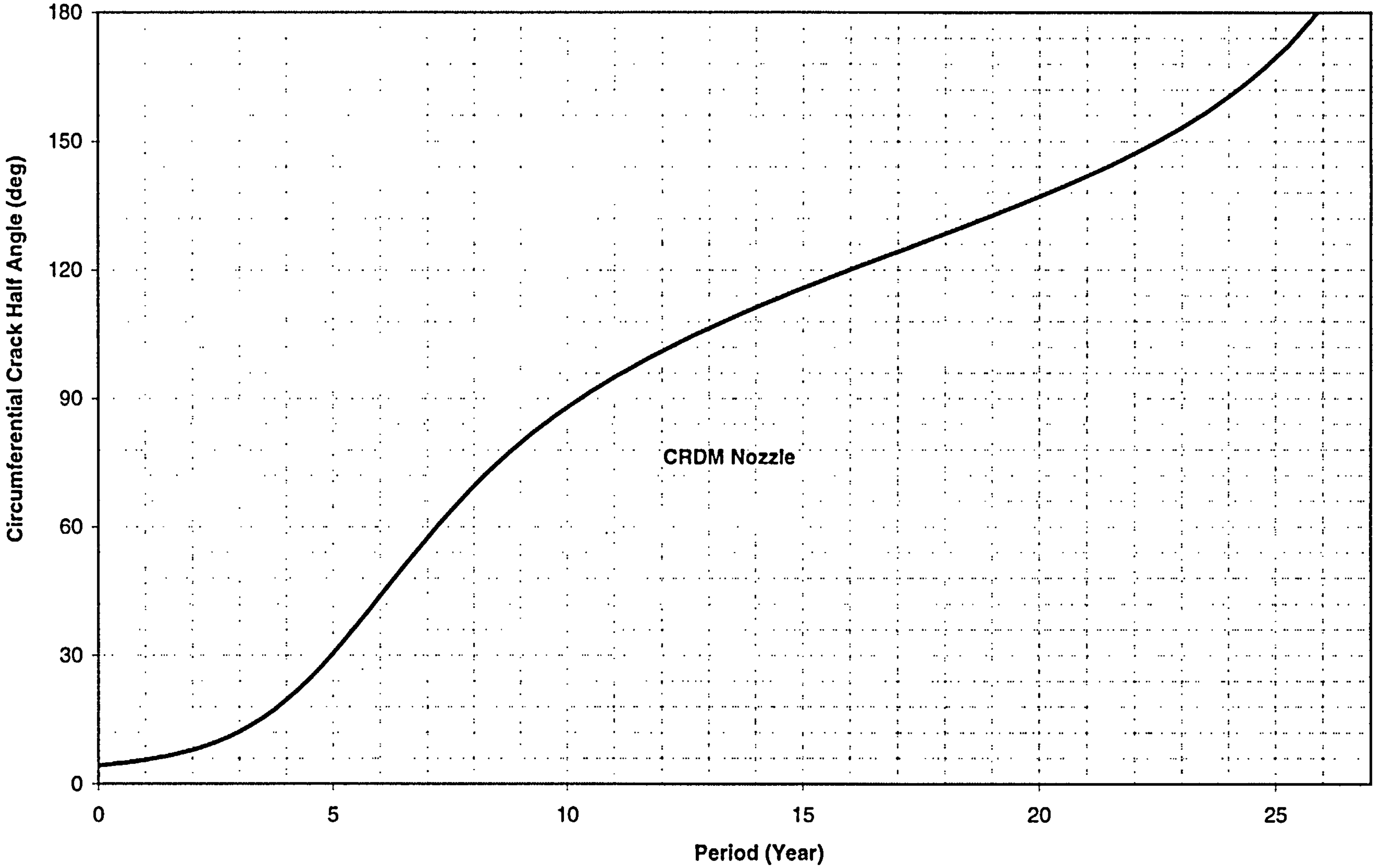

Figure 6-21 Through-Wall Circumferential Flaws Near the Top of the Attachment Weld for CRDM Nozzles - Crack Growth Predictions (MRP Factor of 2.0 Included)

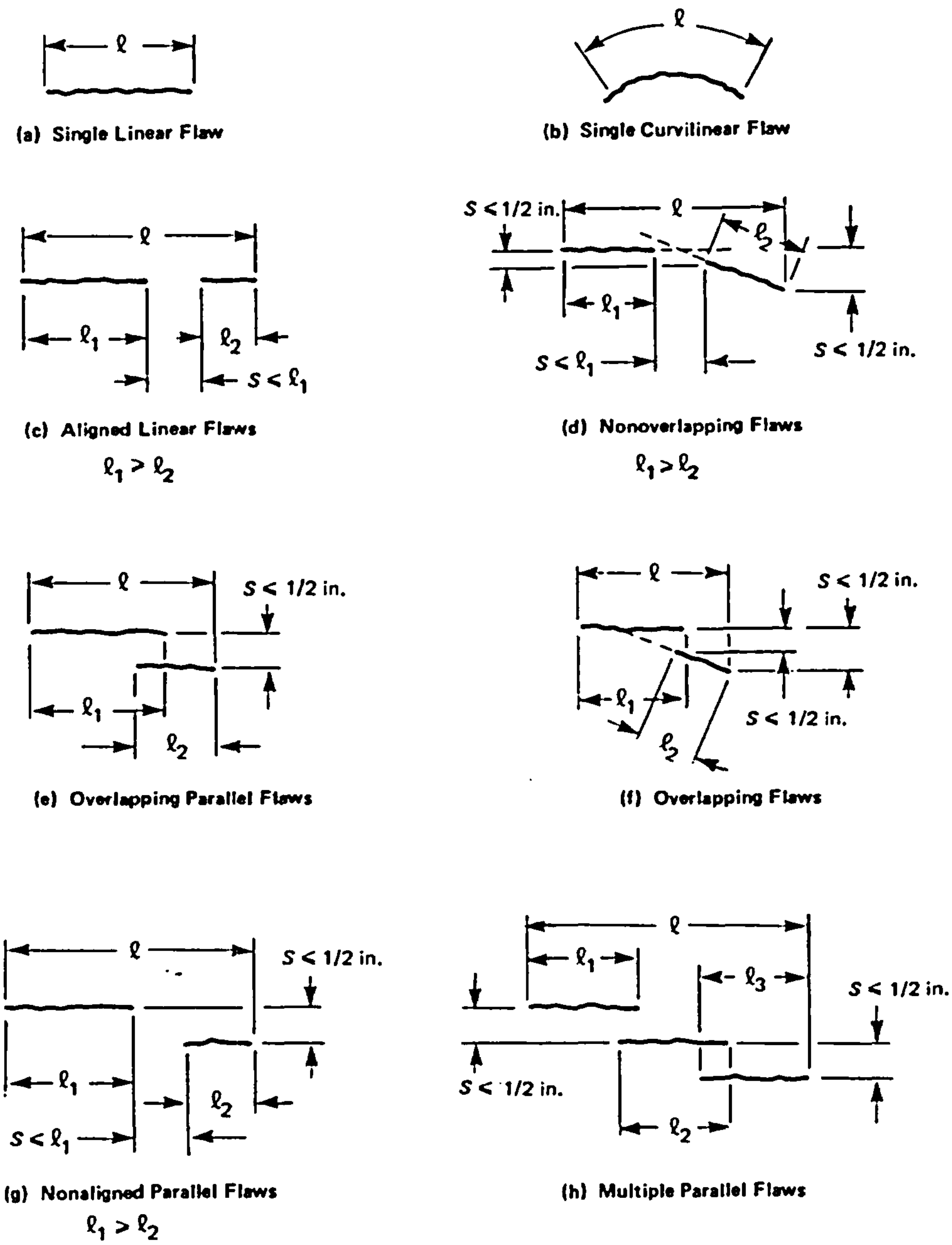

Figure 6-22 Section XI Flaw Proximity Rules for Surface Flaws (Figure IWA-3400-1)

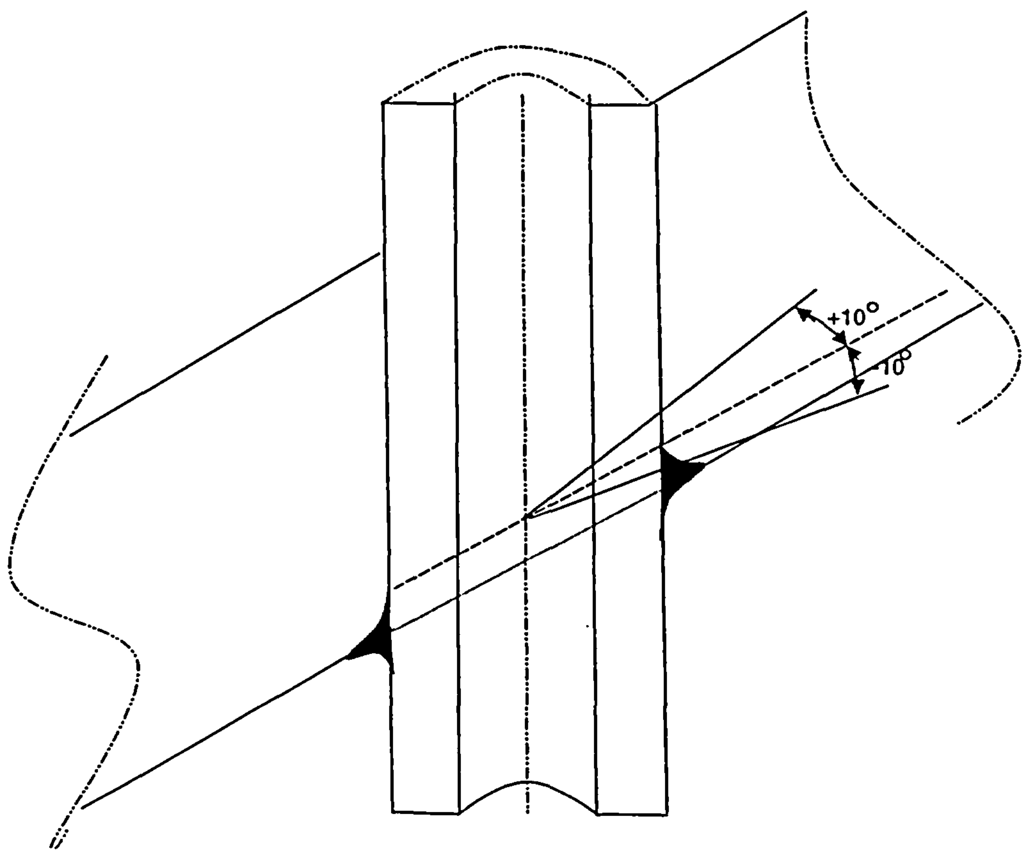

Figure 6-23 Definition of "Circumferential"

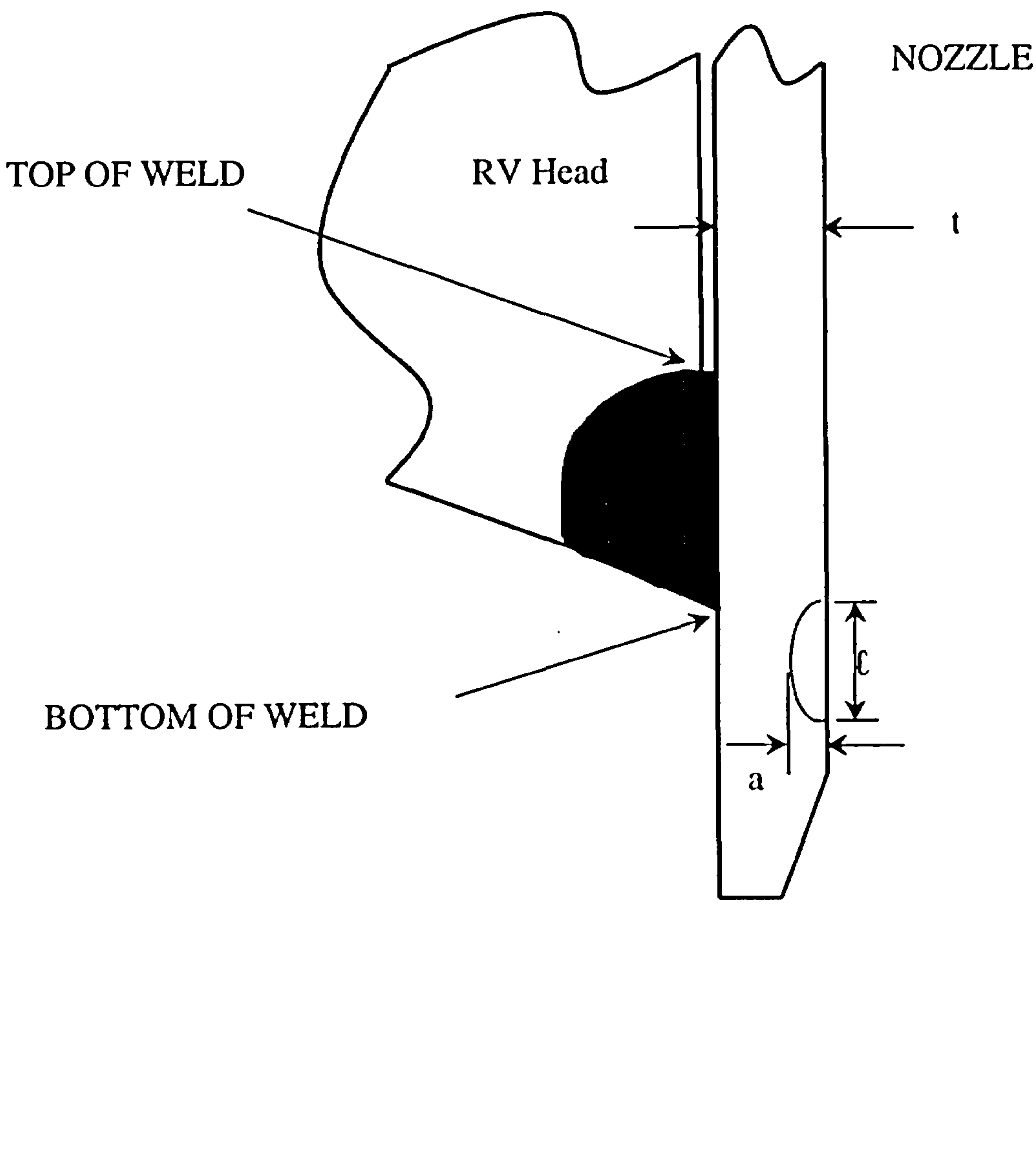

Figure 6-24 Schematic of Head Penetration Geometry

7 SUMMARY

An extensive evaluation has been carried out to characterize the loads and stresses that exist in the head penetrations at Turkey Point Units 3&4. Three-dimensional finite element models were constructed, and all pertinent loads on the penetrations were analyzed [6]. These loads included internal pressure and thermal expansion effects typical of steady state operation. In addition, residual stresses due to the welding of the penetrations to the vessel head were considered.

Results of the analyses reported here are consistent with the axial orientation and location of flaws that have been found in service in a number of plants. The largest stress component is the hoop stress and the maximum stresses were found to exist at the attachment weld. The most important loading conditions were found to be those which reside on the penetration for the majority of the time. These conditions are the steady state loading and the residual stresses.

These stresses are important because the cracking that has been observed to date in operating plants has been determined to result from primary water stress corrosion cracking (PWSCC). These stresses were used in the fracture mechanics calculations to predict the future growth of flaws postulated to exist in the head penetrations. A crack growth law was developed specifically for the operating temperature of the vessel head at Turkey Point Units 3&4 based on the EPRI recommendation, which is consistent with laboratory data as well as crack growth results for operating plants.

The crack growth predictions contained in Section 6 show that the future growth of cracks which might be found in the penetrations will be typically moderate, however, a number of effective full power years would be required for any significant extensions.

The examples in Appendix C show that the most important figures used in evaluating the detected flaws in the head penetrations are Figures 6-2 through 6-10 for the axial surface flaws, and Figure 6-11 for circumferential flaws postulated near the top of the attachment weld. Figures 6-12 through 6-20 provide valuable information on the projected growth of through-wall flaws, but may be of limited practical application with the current acceptance criteria. However, there is an important safety aspect to the through-wall flaw evaluation charts in that they demonstrate that flaw propagation above the weld will be very limited.

The NRC request for additional information in regards to relaxation from Order EA-03-009 for Turkey Point Unit 3 Docket No. 50-250 can be found in Appendix E. Likewise, the Westinghouse responses to the NRC questions that pertain to this WCAP are found in Appendix E. Approval of the request for relaxation can be found in Appendix F of this WCAP.

7.1 SAFETY ASSESSMENT

It is appropriate to examine the safety consequences of an indication that might be found. The indication, even if it were to propagate through the penetration nozzle wall, would have only minor consequences since the pressure boundary would not be broken, unless it were to propagate above the weld.

Further propagation of the indication would not change its orientation, since the hoop stresses in the penetration nozzle are much larger than the axial stresses. Therefore, it is extremely unlikely that the head penetration would be severed.

If the indication were to propagate to a position above the weld, a leak could result, but the magnitude of such a leak would be very small, because the crack could not open significantly due to the tight fit between the penetration nozzle and the vessel head. Such a leak would have no immediate impact on the structural integrity of the system, but could lead to wastage in the ferritic steel of the vessel head as the borated primary water concentrates due to evaporation. Davis Besse has demonstrated the consequence of ignoring such leaks.

Any indication is unlikely to propagate very far up the penetration nozzle above the weld since the hoop stresses decrease in this direction, causing the indication to slow down and stop before it reaches the outside surface of the head.

The high likelihood that the indication will not propagate up the penetration nozzle beyond the vessel head ensures that no catastrophic failure of the head penetration will occur. The indication will be enveloped in the vessel head itself, which precludes the opening of the crack and limits leakage.

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4G. [ ]^{a,c,e}

4H. "Materials Reliability Program (MRP) Crack Growth Rates for Evaluating Primary Water Stress Corrosion Cracking (PWSCC) of Thick Wall Alloy 600 Material (MRP-55) Revision 1," EPRI, Palo Alto, CA: 2002. 1006695.

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6. [
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APPENDIX A

ALLOWABLE AREAS OF LACK OF FUSION: WELD FUSION ZONES

There are two fusion zones of interest for the head penetration nozzle attachment welds, the penetration nozzle itself (Alloy 600) and the reactor vessel head material (A533B ferritic steel). The operating temperature of the upper head region of the Turkey Point Units 3&4 is 312°C (594°F) and the materials will be very ductile. The toughness of both materials is quite high and any flaw propagation along either of the fusion zones will be totally ductile.

Two generic calculations were completed for the fusion zones, one for the critical flaw size, and the second one for the allowable flaw size, which includes the margins required in the ASME code. The simpler case is the Alloy 600 fusion zone, where the potential failure will be a pure shearing of the penetration as the pressurized penetration nozzle is forced outward from the vessel head, as shown in Figure A-1.

The failure criterion will be that the average shear stress along the fusion line exceeds the limit shear stress. For the critical flaw size, the limiting shear stress is the shear flow stress, which is equal to half the tensile flow stress, according to the Tresca criterion. The tensile flow stress is the average of the yield stress and ultimate tensile stress of the material. The criterion for Alloy 600 tubes in the upper head region is:

$$\text{Average shear stress} < \text{shear flow stress} = 26.85 \text{ ksi}$$

This value was taken from the ASME Code, Section III, Appendix I, at 600°F.

For each penetration, the axial force, which produces this shear stress, results from the internal pressure. Since each penetration has the same outer diameter, the axial force is the same. The average shear stress increases as the load carrying area decreases (the area of lack of fusion increases). When this increasing lack of fusion area increases the stress to the point at which it equals the flow stress, failure occurs. This point may be termed the critical flaw size. This criterion is actually somewhat conservative. Alternatively, use of the Von Mises failure criterion would have set the shear flow stress equal to 60 percent of the axial flow stress, and would therefore have resulted in larger critical flaw sizes.

The allowable flaw size, as opposed to the critical flaw size discussed above, was calculated using the allowable limit of Section III of the ASME Code, paragraph NB 3227.2. The criterion for allowable shear stress then becomes:

$$\text{Average shear stress} < 0.6\ S_m = 13.98 \text{ ksi}$$

where:

S_m = the ASME Code limiting design stress from Section III, Appendix I.

The above approach was used to calculate the allowable flaw size and critical flaw size for the outermost and center penetrations. The results show that a very large area of lack of fusion can be tolerated by the head penetrations, regardless of their orientation. These results can be illustrated for the outermost CRDM penetration.

The total surface contact area for the fusion zone on the outermost head penetration is 17.4 in^2. The calculations above result in a required area to avoid failure of only 1.45 in^2, and using the ASME Code criteria, the area required is 2.79 in^2. These calculations show that as much as 83.9 percent of the weld may be unfused, and the code acceptance criteria can still be met.

To envision the extent of lack of fusion allowed, Figure A-2 was prepared. In this figure, the weld fusion region for the outermost penetration has been shown in an unwrapped, or developed view. The figure shows the extent of lack of fusion allowed in terms of limiting lengths for a range of circumferential lack of fusion. This figure shows that the allowable vertical length of lack of fusion for a full circumferential unfused region is 84 percent of the weld length. Conversely, for a region of lack of fusion extending the full vertical length of the weld, the circumferential extent is limited to 302 degrees. The extent of lack of fusion which would cause failure is labeled "critical" on this figure, and is even larger. The dimensions shown on this figure are based on an assumed rectangular area of lack of fusion.

The full extent of this allowable lack of fusion is shown in Figure A-3, where the axes have been expanded to show the full extent of the head penetration-weld fusion line. This figure shows that a very large area of lack of fusion is allowed for the outer most penetration. Similar results were found for the center penetration, where the weld fusion area is somewhat smaller at 16.1 in^2.

A similar calculation was also carried out for the fusion zone between the weld and the vessel head, and the result is shown in Figure A-4. The allowable area of unfused weld for this location is 84.8 percent of the total area. This approach to evaluating the fusion zone with the carbon steel vessel head is only approximate, but may provide a realistic estimate of the allowable. Note that even a complete lack of fusion in this region would not result in penetration nozzle ejection, because the weld to the head penetration would prevent the penetration nozzle from moving up through the vessel head.

The allowable lack of fusion for the weld fusion zone to the vessel head using the approximate approach may be somewhat in doubt, because of the different geometry, where one cannot ensure that the failure would be due to pure shear. To investigate this concern, additional finite element models were constructed with various degrees of lack of fusion discretely modeled, ranging from 30 to 65 percent. The stress intensities around the circumference of the penetration were calculated to provide for the effects of all the stresses, as opposed to the shear stress only, as used above. When the average stress intensity reaches the flow stress (53.7 ksi), failure is expected to occur. The code allowable stress intensity is 1.5 S_m, or 35 ksi, using the lower of the Alloy 600 and ferritic allowables at 316°C (600°F).

The results of this series of analyses are shown in Figure A-5, where it is clear that large areas of lack of fusion are allowed. As the area of lack of fusion increases, the stresses redistribute themselves, and that the stress intensity does not increase in proportion to the area lost. These results seem to confirm that shear stress is the only important stress governing the critical flaw size for the vessel head fusion zone as well.

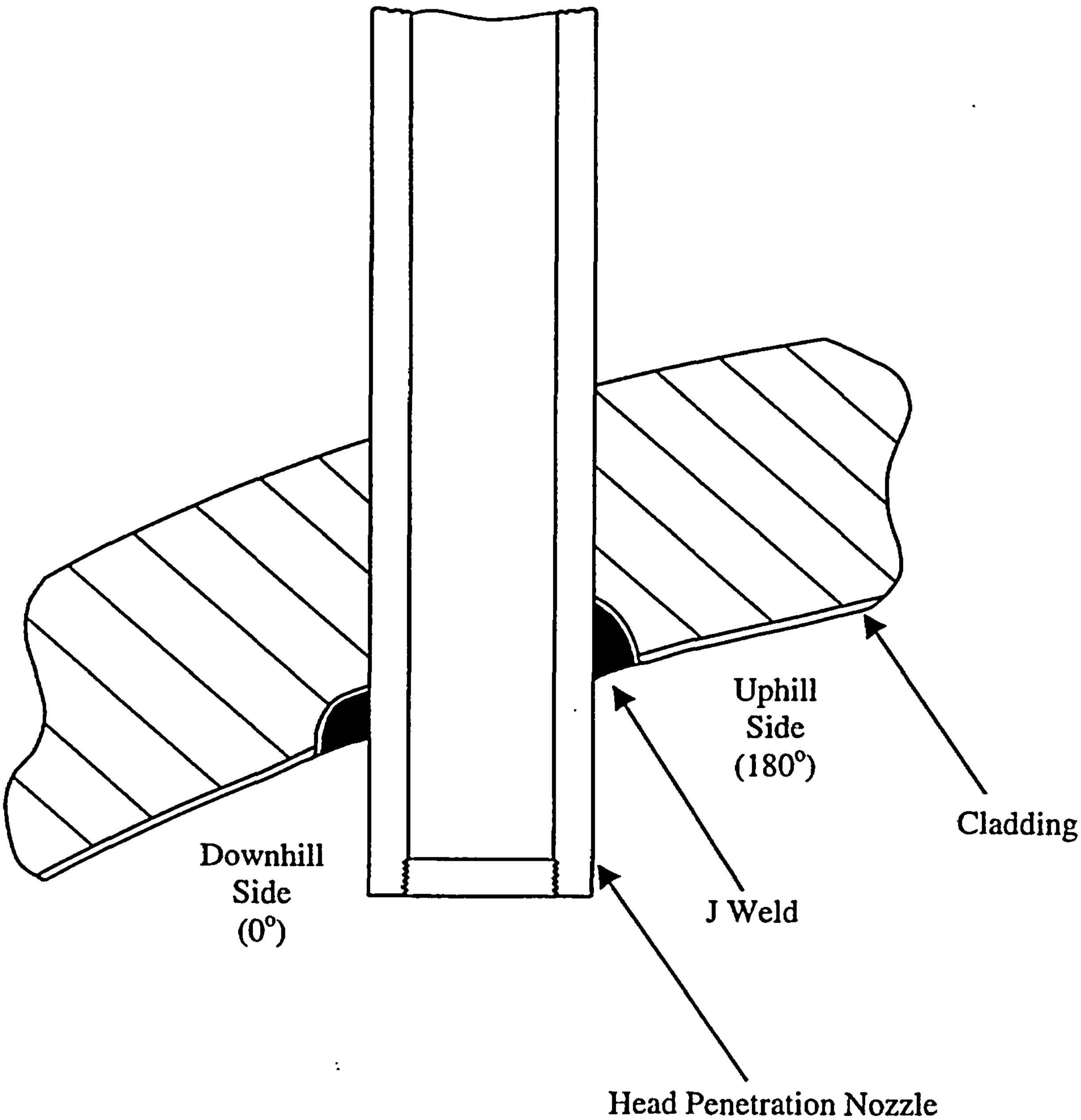


Figure A-1 Typical Head Penetration

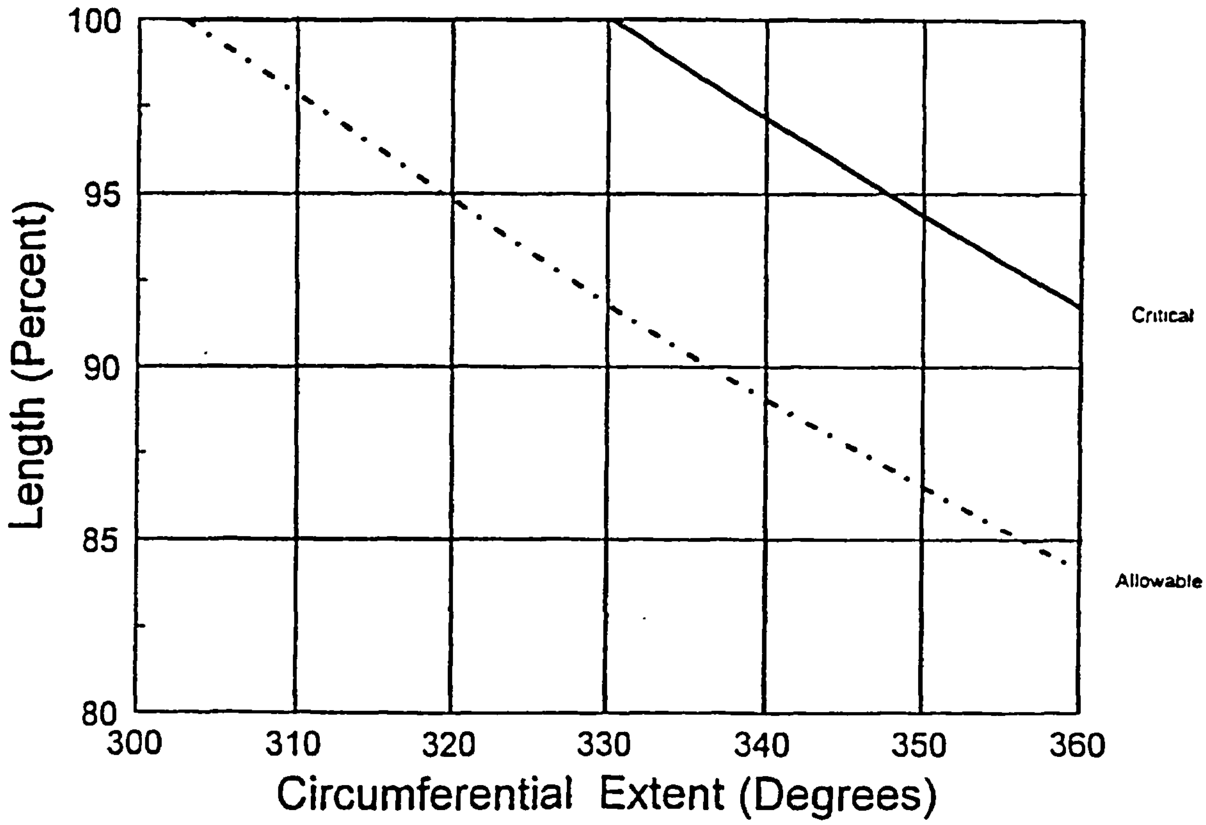


Figure A-2 Allowable Regions of Lack of Fusion for the Outermost Penetration Tube to Weld Fusion Zone: Detailed View

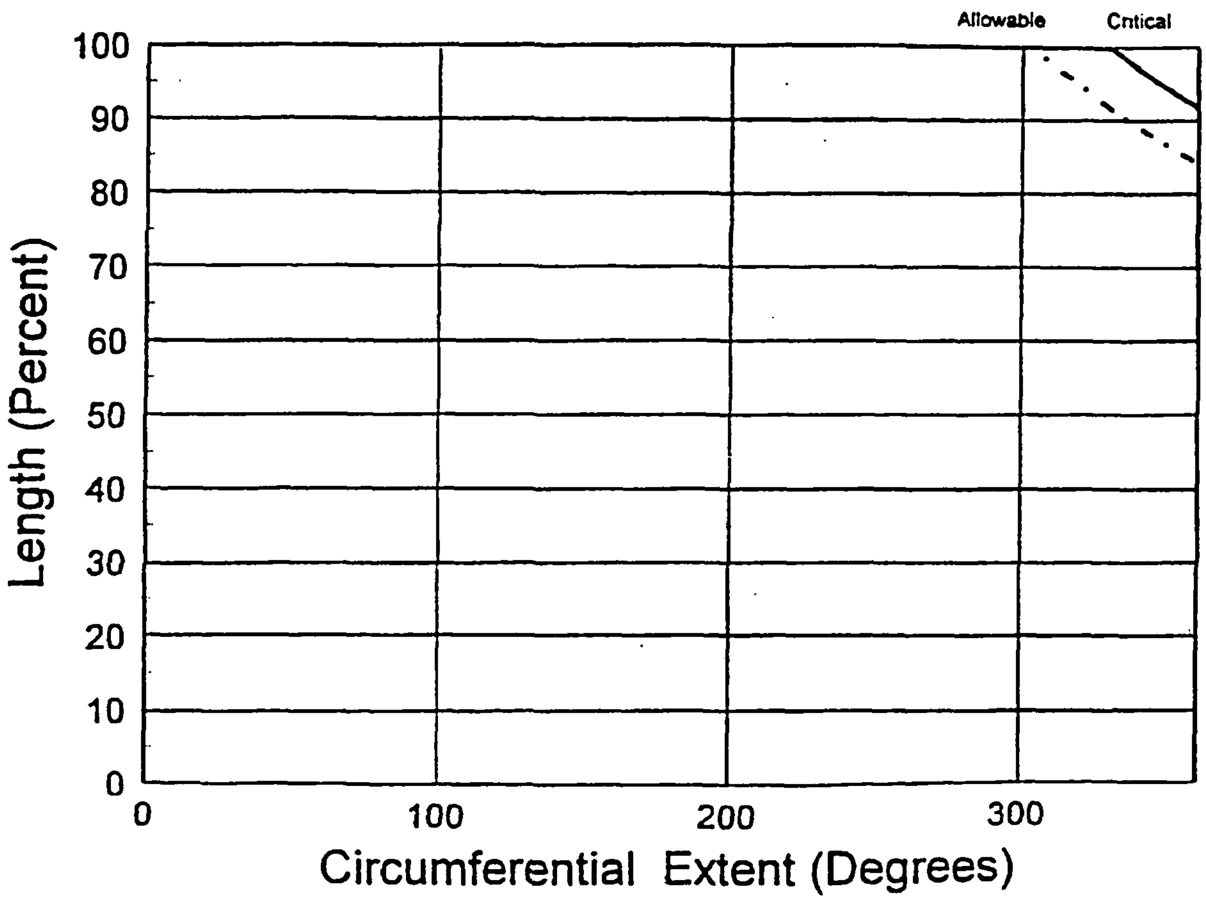


Figure A-3 Allowable Regions of Lack of Fusion for the Outermost Penetration Tube to Weld Fusion Zone

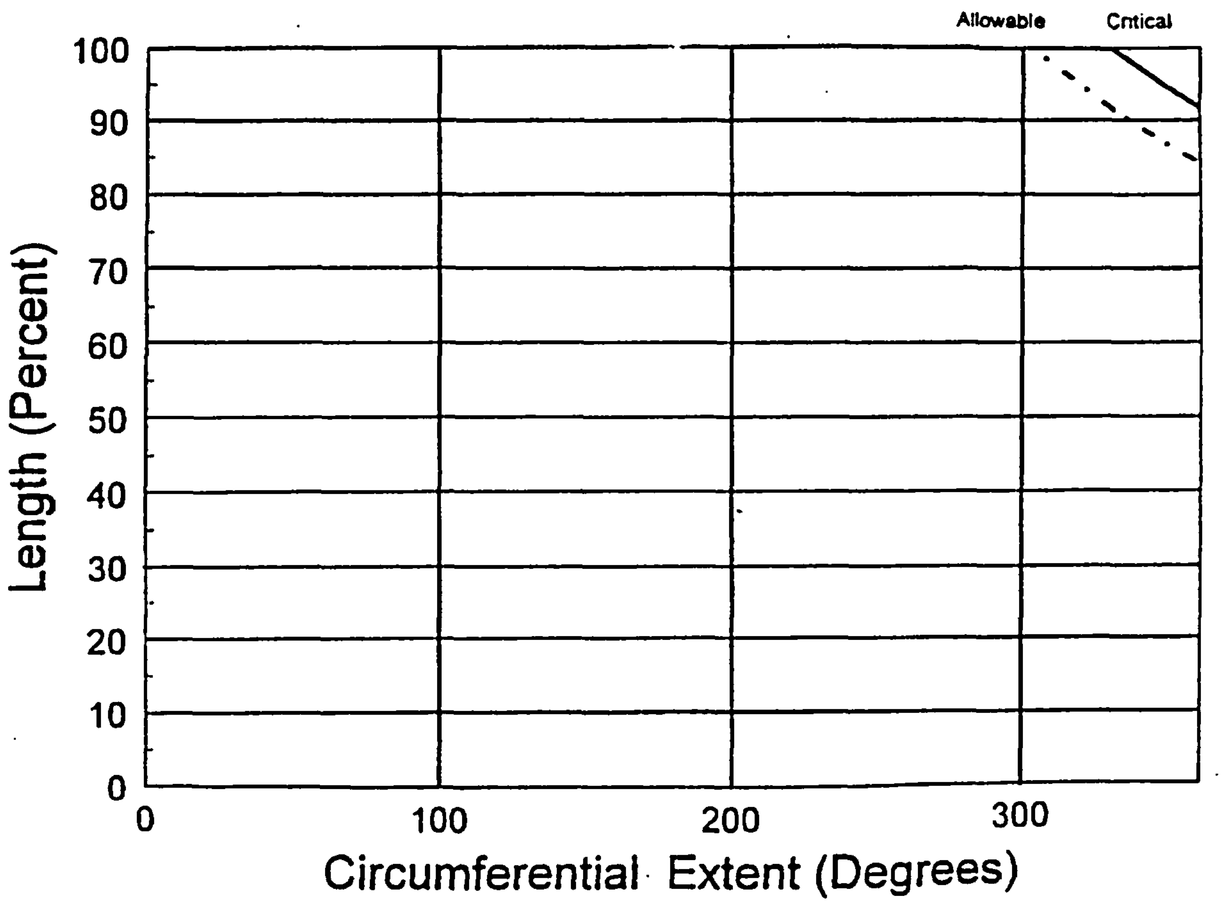


Figure A-4 Allowable Regions of Lack of Fusion for all Penetrations: Weld to Vessel Fusion Zone

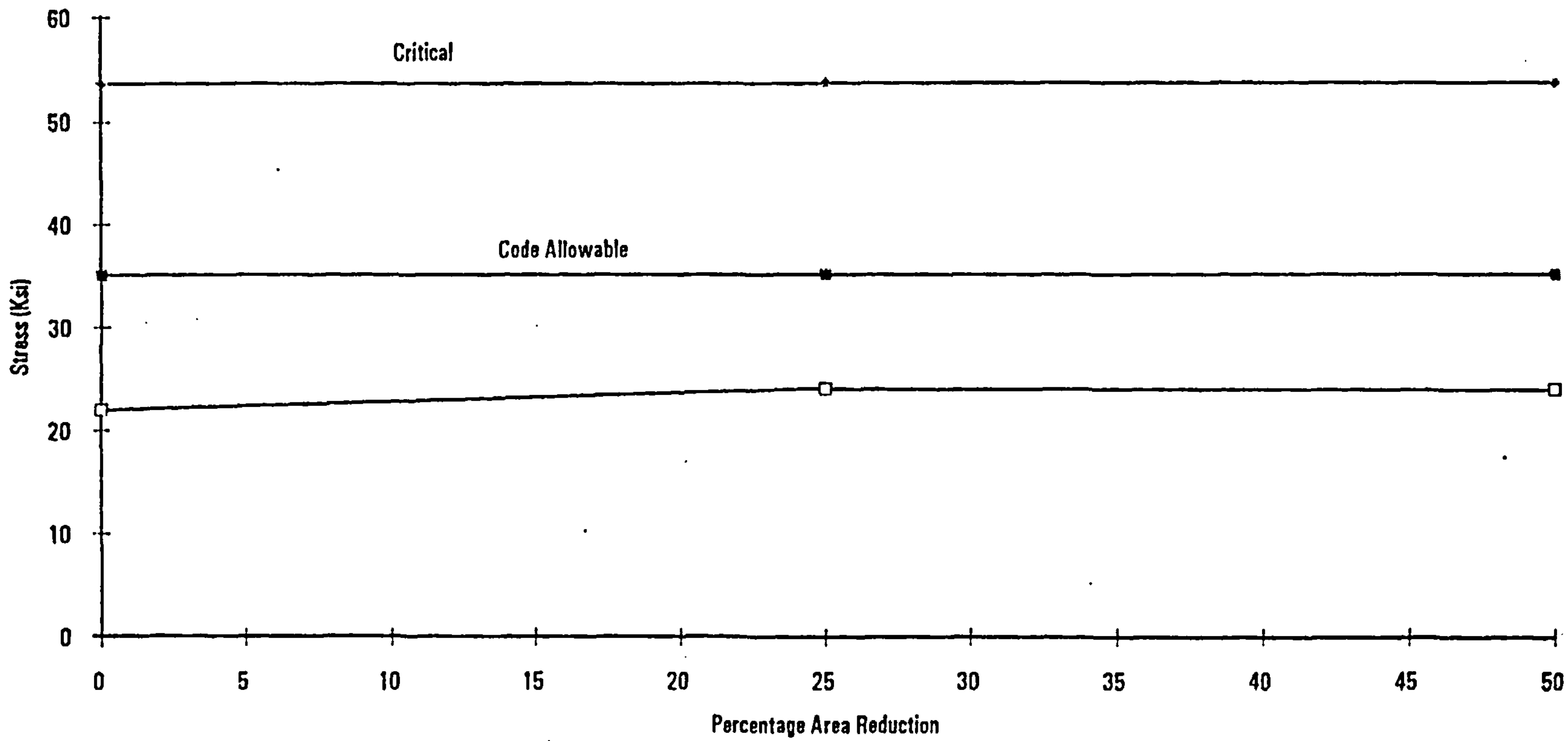


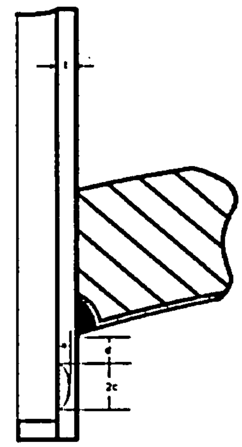
Figure A-5 Allowable Regions of Lack of Fusion for the Weld to Vessel Fusion Zone

APPENDIX B

FLAW TOLERANCE EVALUATION GUIDELINES

The following guidelines are provided to assist in determining the allowable service time for a typical flaw found during inspections. The section entitled "Additional guidelines" is provided to assist in evaluating flaws not specifically covered in the enclosed flaw tolerance charts.

Definition of Terms



a = Flaw depth.

t = Wall thickness (0.625 inches for CRDM, 0.122 for Head Vent).

a/t = Ratio of flaw depth to wall thickness.

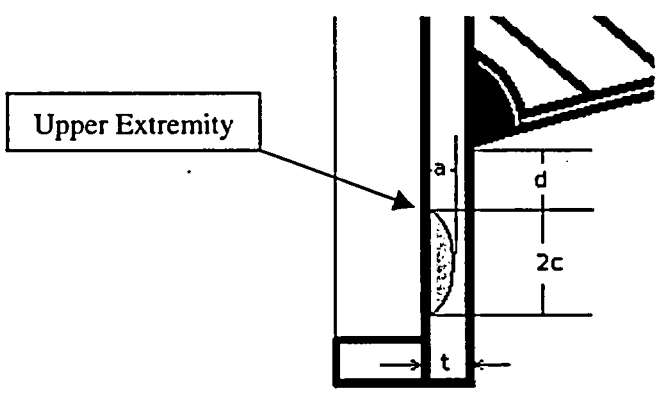
d = Distance below or above the weld (See diagram below)

c = Flaw half-length (2c shall be the full length of the flaw)

aspect ratio = 2c/a = Flaw length / depth

The subscript "initial" refers to the state at which the flaw is found

The subscript "final" refers to the state at which the flaw has reached the acceptance criteria (Table 6-1)



Procedure I (See Example 3 in Appendix C)

Used For:
- *Inside, Axial Surface Flaws At the Attachment Weld*
- *Inside, Axial Surface Flaws 0.5" or More Above the Weld*

1. Determine Location and Orientation of the Flaw
   - Axial or Circumferential
   - Inside or Outside Surface
   - Above, At or Below Attachment Weld
   - Uphill or Downhill

2. Go to Table 1-1 to obtain the Penetration Nozzle Locality Angle

3. Identify the Applicable Flaw Tolerance Chart(s)
   - At the Weld
   - 0.5" Above the Weld

4. Determine the Ratio $a_{initial}/t$ (Flaw Depth / Wall Thickness)

5. Determine the Initial Reference Time for the Flaw
   - Draw a horizontal line intersecting the vertical axis at the value of $a_{initial}/t$
   - Draw a vertical line downward at the point where the horizontal line intersects the applicable penetration nozzle locality angle curve.
   - The initial reference time for the flaw is where the vertical line intersects the horizontal axis.

6. Go to Table 6-1 to Determine Acceptance Criteria
   - Acceptance criteria will provide the final allowable flaw depth (a_{final})
   - Determine the acceptable a_{final}/t ratio

7. Determine the Final Reference Time for the Flaw
   - Draw a horizontal line intersecting the vertical axis at value of allowable a_{final}/t
   - Draw a vertical line downward at the point where the horizontal line intersects the applicable penetration nozzle locality angle curve.
   - The final reference time for the flaw is where the vertical line intersects the horizontal axis.

8. Determine the Remaining Service Life
   - Remaining Service Life = Final Reference Time – Initial Reference Time

Procedure II (See Examples 1 and 4 in Appendix C)

Used For:

- *Inside, Axial Surface Flaws 0.5" or More Below the Attachment Weld*

Inside, Axial Surface flaws 0.5" or more below the attachment weld may require the use of more than one flaw tolerance chart. The following guidelines can be used to determine the remaining service life if the flaw length ($2c_{final}$) grows within 0.5" below the weld before the flaw depth (a_{final}) reaches the acceptance criteria (Table 6-1).

1. Determine the final length of the flaw ($2c_{final}$)
   - Assume initial aspect ratio ($2c_{initial}/a_{initial}$) is maintained
   - Determine allowable flaw depth (a_{final}) based on acceptance criteria (Table 6-1)
   - Final length equals the product of aspect ratio and allowable flaw depth

$$2c_{final} = \frac{2c_{initial}}{a_{initial}} \cdot a_{final}$$

2. Determine the distance between the upper extremity of the flaw and the bottom of the weld

$$d_{final} = d_{initial} - (c_{final} - c_{initial})$$

3. Determine if the flaw will grow within 0.5" below the weld
   - If $d_{final} \geq 0.5"$, the flaw will not grow within 0.5" below the weld and the remaining service life can be determined using the guidelines for Procedure I.
   - If $d_{final} < 0.5"$, separate charts should be used for the time that the upper extremity grows to 0.5" below the weld, and the time that it grows from 0.5" below the weld to the acceptance criteria (Table 6-1). Evaluation continues with Step 4 of this section.

4. Determine Location of the Flaw
   - Uphill or Downhill

5. Go to Table 1-1 to obtain the Penetration Nozzle Locality Angle

6. Identify the Applicable Flaw Tolerance Charts
   - At the Weld and 0.5" Below the Weld

7. Determine the Ratio a/t when the upper extremity of the flaw is 0.5" below the weld.
   - Assume initial aspect ratio ($2c_{initial}/a_{initial}$) is maintained.
   - Determine flaw length ($c_{0.5" below}$) when upper extremity reaches 0.5" below the weld.

$$c_{0.5" below} = c_{initial} + d_{initial} - 0.5$$

   - Determine flaw depth ($a_{0.5" below}$) at which the upper extremity reaches 0.5" below the weld.

$$a_{0.5" below} = 2c_{0.5" below} \cdot (a_{initial} / 2c_{initial})$$

   - Determine ratio a/t

$$\text{Ratio} = a_{0.5" below} / t$$

8. Determine the initial reference time for the flaw (use 0.5" below the weld flaw tolerance chart)
    - Draw a horizontal line intersecting the vertical axis at the value of $a_{initial}/t$.
    - Draw a vertical line downward at the point where the horizontal line intersects the applicable penetration nozzle locality angle curve.
    - The initial reference time for the flaw is where the vertical line intersects the horizontal axis.

9. Determine the final reference time for the flaw to grow to 0.5" below the weld (use 0.5"below the weld flaw tolerance chart)
    - Draw a horizontal line intersecting the vertical axis at value of $a_{0.5"\ below}/t$.
    - Draw a vertical line downward at the point where the horizontal line intersects the applicable penetration nozzle locality angle curve.
    - The final reference time for the flaw is where the vertical line intersects the horizontal axis.

10. Determine the Service Life for the flaw to grow to 0.5" below the weld

    $$\text{Service Life}_{0.5"\ below} = \text{Final Reference Time}_{0.5"\ below} - \text{Initial Reference Time}_{0.5"\ below}$$

11. Go to Table 6-1 to Determine Acceptance Criteria
    - Acceptance criteria will provide the final allowable flaw depth (a_{final})
    - Determine the acceptable a_{final}/t ratio

12. Determine the initial reference time for the flaw to grow from 0.5" below the weld to the acceptance criteria (use at the weld flaw tolerance chart)
    - Draw a horizontal line intersecting the vertical axis at the value of $a_{0.5"\ below}/t$.
    - Draw a vertical line downward at the point where the horizontal line intersects the applicable penetration nozzle locality angle curve.
    - The initial reference time for the flaw is where the vertical line intersects the horizontal axis.

13. Determine the final reference time for the flaw to grow from 0.5" below the weld to the acceptance criteria (use the at the weld flaw tolerance chart)
    - Draw a horizontal line intersecting the vertical axis at value of a_{final}/t.
    - Draw a vertical line downward at the point where the horizontal line intersects the applicable penetration nozzle locality angle curve.
    - The final reference time for the flaw is where the vertical line intersects the horizontal axis.

14. Determine the Service Life for the flaw to grow from 0.5" below the weld to the acceptance criteria.

    $$\text{Service Life}_{at\ weld} = \text{Final Reference Time}_{at\ weld} - \text{Initial Reference Time}_{at\ weld}$$

15. Determine the Remaining Service Life

    $$\text{Remaining Service Life} = \text{Service Life}_{0.5"\ below} + \text{Service Life}_{at\ weld}$$

See the additional guidelines for a quicker, yet more conservative, evaluation of flaws 0.5" below the attachment weld that cross zones before reaching the acceptance criteria.

Procedure III (See Example 2 in Appendix C)

Used For:

- *Outside, Axial Surface Flaws Below the Attachment Weld*

Outside, Axial Surface flaws below the attachment weld may have a flaw length ($2c_{final}$) that will grow into the weld before its depth (a_{final}) can reach the acceptance criteria criteria (Table 6-1). If this is the case, the following guidelines can be used to determine the remaining service life.

1. Determine the final length of the flaw ($2c_{final}$)
   - Assume initial aspect ratio ($2c_{initial}/a_{initial}$) is maintained
   - Determine allowable flaw depth (a_{final}) based on acceptance criteria (Table 6-1)
   - Final length equals the product of aspect ratio and allowable flaw depth

$$2c_{final} = \frac{2c_{initial}}{a_{initial}} \cdot a_{final}$$

2. Determine the distance between the upper extremity of the flaw and the bottom of the weld

$$d_{final} = d_{initial} - (c_{final} - c_{initial})$$

3. Determine if the flaw will grow into the weld
   - If $d_{final} > 0$, the flaw will not grow into the weld and the remaining service life can be determined using the guidelines for Procedure I.
   - If $d_{final} \leq 0$, the flaw will grow into the weld and evaluation continues with Step 4 of this section.

4. Determine Location of the Flaw
   - Uphill or Downhill

5. Go to Table 1-1 to obtain the Penetration Nozzle Locality Angle

6. Identify the Applicable Flaw Tolerance Charts
   - Outside Surface, Below the Attachment Weld

7. Determine the Ratio a/t when the upper extremity of the flaw at the weld.
   - Assume initial aspect ratio ($2c_{initial}/a_{initial}$) is maintained.
   - Determine flaw length ($c_{bottom\ of\ weld}$) when upper extremity reaches the weld.

$$C_{bottom\ of\ weld} = c_{initial} + d_{initial}$$

   - Determine flaw depth ($a_{at\ weld}$) at which the upper extremity reaches the weld.

$$a_{bottom\ of\ weld} = 2c_{bottom\ of\ weld} \cdot (a_{initial} / 2c_{initial})$$

   - Determine ratio a/t

$$Ratio = a_{bottom\ of\ weld} / t$$

8. Determine the initial reference time for the flaw (use below the weld flaw tolerance chart)
   - Draw a horizontal line intersecting the vertical axis at the value of $a_{initial}/t$.
   - Draw a vertical line downward at the point where the horizontal line intersects the applicable penetration nozzle locality angle curve.
   - The initial reference time for the flaw is where the vertical line intersects the horizontal axis.

9. Determine the final reference time for the flaw to grow to the weld (use below the weld flaw tolerance chart)
   - Draw a horizontal line intersecting the vertical axis at value of $a_{bottom\ of\ weld}/t$.
   - Draw a vertical line downward at the point where the horizontal line intersects the applicable penetration nozzle locality angle curve. The final reference time for the flaw is where the vertical line intersects the horizontal axis.

10. Determine the Service Life for the flaw to grow to the weld

$$\text{Service Life}_{bottom\ of\ weld} = \text{Final Reference Time}_{bottom\ of\ weld} - \text{Initial Reference Time}_{bottom\ of\ weld}$$

Procedure IV (See Example 5 in Appendix C)

Used For:

- *Axial Through-Wall Flaws Below the Weld*

1. Go to Table 1-1 to obtain the Penetration Nozzle Locality Angle

2. Identify the Applicable Flaw Tolerance Chart(s)
    - Nozzle Locality Angle
    - Uphill or Downhill

3. Determine the Initial Reference Time for the Flaw
    - Draw a horizontal line intersecting the vertical axis at the value corresponding to the location of the crack tip with respect to the bottom weld.
    - Draw a vertical line downward at the point where the horizontal line intersects the applicable penetration nozzle locality angle curve.
    - The initial reference time for the flaw is where the vertical line intersects the horizontal axis.

4. Determine the Final Reference Time for the Flaw
    - Draw a vertical line downward at the point where the CRDM bottom weld horizontal line intersects the penetration nozzle locality angle curve.
    - The final reference time for the flaw is where the vertical line intersects the horizontal axis.

5. Determine the Remaining Service Life
    - Remaining Service Life = Final reference Time – Initial Reference Time

Additional Guidelines

1. If a flaw is found in a penetration nozzle for which no specific analysis was performed and there is a uniform trend as a function of penetration nozzle angle, interpolation between penetration nozzles is the best approach.

2. If a flaw is found in a penetration nozzle for which no specific analysis was performed and there is no apparent trend as a function of penetration nozzle angle, the result for the penetration nozzle with the closest angle should be used.

3. If a flaw is found which has a depth smaller than any depth shown for the penetration nozzle angle of interest, the initial flaw depth should be assumed to be the same as the smallest depth analyzed for that particular penetration nozzle.

4. The flaw evaluation charts are applicable for aspect ratio of 6 or less. Consult with Westinghouse if the as-found flaw has an aspect ratio larger than 6.0.

5. In the Procedure II guidelines, flaws whose upper extremities grow within 0.5" below the weld require the use of both the 0.5" below the weld and "at the weld" flaw tolerance charts. To avoid the use of these two charts, the "at the weld" charts may solely be used in determining the service life. This shall provide a conservative estimate of the crack growth due to a larger stress field.

6. All references to service life are in effective full power years.

7. Results are only provided for the uphill and downhill sides of the selected penetration nozzles. If flaws are found in locations between the uphill and downhill side, use the results for either the uphill or downhill location, whichever is closer.

APPENDIX C

EXAMPLE PROBLEMS

The flaw tolerance charts in Figures 6-2 through 6-21 can be used with the acceptance criteria of Section 6.5 to determine the available service life. This appendix uses the guidelines of Appendix B to present a few examples illustrating the use of these figures. The example cases are listed in Table C-1.

Example 1 – Determine the service life of an axially oriented inside surface flaw whose upper extremity is located 1.2" below the weld on the uphill side of penetration no. 30 with an initial flaw depth of 0.078" ($a_{initial}$) and an initial flaw length of 0.195" ($2c_{initial}$). First, we must assume that the initial aspect ratio of 2.5:1 (0.078/0.195) is maintained throughout the time that the inside surface flaw becomes a through-wall flaw. The final length of the flaw ($2c_{final}$) will be 1.563" ((0.78/0.195)*0.625). The upper extremity of the flaw is now located 0.516" (1.2-((1.563/2)-(0.195/2))) below the weld and validates the use of a single crack growth curve. The penetration locality angle is then obtained from Table 1-1 (28.6 degrees). The crack growth curve for the nozzle angle of Figure 6-2 is applicable and Figure 6-2 has been reproduced as Figure C-1. The flaw is initially 12.5 percent of the wall thickness, and a straight line is drawn horizontally at a/t = 0.125 that intersects the crack growth curve. Using the acceptance criteria in Table 6-1, the service life can then be determined as the remaining time for this flaw to grow to the limit of 100 percent of the wall thickness or approximately 3.75 years (labeled as Service Life in Figure C-1)

Example 2 – In this case, the flaw is identical in size to that used in Example 1, but located on the outside surface and on the downhill side of penetration no. 30. This flaw, just as the flaw in Example 1, will not cross into the weld region. The applicable curve to use is Figure 6-10. The ratio a/t and initial reference time are likewise found using the same approach as used in Example 1. Using the acceptance criteria in Table 6-1, the determination of service life is illustrated in Figure C-2, where we can see that the result is approximately 2.3 years.

Example 3 –An axial inside surface flaw is located at the weld and on the downhill side of penetration no. 1. The initial length of the flaw is 0.234" and the initial depth is 0.047". From Table 1-1, the angle of this penetration nozzle is 0.0 degrees. The applicable curve is Figure 6-5 and is reproduced here as Figure C-3. In this case, the initial flaw depth is 7.5 percent of the wall thickness. The initial reference time can be found by drawing a horizontal line at a/t = 0.075. Using the acceptance criteria in Table 6-1, the allowable service life can then be determined as the time for the flaw to reach a depth of 75 percent of the wall thickness. The final reference time is found through a horizontal line drawn at a/t = 0.75. The service life can be determined through the intersection points of these lines and the crack growth curve. The resulting service life is approximately 3.6 years, as shown in Figure C-3.

Example 4 – In this case, we have postulated an axial inside surface flaw with an upper extremity located 1.0 inch below the attachment weld on the downhill side of penetration no. 30 (28.6 degrees). The flaw has an initial depth of 0.078" and an initial length of 0.394". Assuming that the initial aspect ratio of 5:1 (0.394" / 0.078") is maintained as the flaw propagates into the nozzle wall, the final length of a through-wall flaw would be 3.125" long (0.625" x 5). The location of the upper extremity of this flaw would have reached within 0.5 inch below the weld as it propagates into the nozzle wall (1.0" – ((3.125" / 2) – (0.394" / 2))). Therefore the evaluation will require the use of two flaw charts. The first step is to estimate the time required for the initial flaw to grow to within 0.5 inch of the weld. This can be accomplished with the use of Figure 6-3 and is reproduced here as Figure C-4a. The upper extremity is 1 inch below the weld and is assumed to grow until the extremity is 0.5 inches below the weld. The final half-length of the flaw when it reaches 0.5 inches below the weld will be the sum of the initial half-length and the 0.5 inches it has grown or 0.697" ((0.394 / 2) + 1.0" - 0.5"). Multiplying this by two and then dividing by the aspect ratio ((2 x 0.697") / 5.0) gives the flaw depth (0.279") when the upper extremity is 0.5 inches below the weld. Figure C-4a can be used to find the time it takes to grow from 12.5% through-wall (a/t = 0.0.078" / 0.625 = 0.125) to 45% through-wall (a/t = 0.279/0.625 = 0.45). The time is estimated as 6.1 years. Using the flaw depth calculated previously (a/t = 0.45) as the initial flaw depth, the curves in Figure 6-5, reproduced here as Figure C-4b, for inside surface flaws near the weld can be used to determine the remaining service time before the flaw depth reaches the allowable flaw size. Using the acceptance criteria in Table 6-1, Figure C-4b shows an additional 0.75 years of service life for a total of 6.9 years (Consult additional guidelines #5 for a simplified, more conservative approach).

Example 5 – This case is an axial through-wall flaw with its upper extremity located 0.40 inches below the weld region on the uphill side of penetration no. 69. The angle of the penetration nozzle is 42.6 degrees as shown in Table 1-1. The crack growth curves of Figure 6-19 are applicable and has been reproduced as Figure C-5. The initial reference time is found by drawing a horizontal line 0.40 inches below the line representing the bottom of the weld, then dropping a vertical line to the x axis. The final reference time is found by drawing a vertical line where the crack growth curve intersects the bottom of the weld horizontal line. The service life is estimated to be approximately 2.5 years for the initial flaw to grow to the bottom of the attachment weld.

The examples show that the most important figures used in evaluating the detected flaws in the head penetrations are Figures 6-2 through 6-10 for the axial surface flaws, and Figure 6-11 for circumferential flaws postulated near the top of the attachment weld. Figures 6-12 through 6-20 provide valuable information on the projected growth of through-wall flaws, but may be of limited practical application with the current acceptance criteria. However, there is an important safety aspect to the through-wall flaw evaluation charts in that they demonstrate that flaw propagation above the weld will be very limited.

Table C-1 Example Problem Inputs: Initial Flaw Sizes and Locations											
No.	**Orientation**	**Vertical Location**	**Circum. Location**	**Penetration Angle**	**Length (2c)**	**Depth (a)**	**a/t**	**Asp. Ratio**	**Wall Thick. (t)**	**Pen. No.**	**Source Figure**
1	Axial - Inside Surface	1.2" Below Weld	Uphill	28.6°	0.195"	0.078"	0.125	2.5:1	0.625"	30	6-2
2	Axial - Outside Surface	1.2" Below Weld	Downhill	28.6°	0.195"	0.078"	0.125	2.5:1	0.625"	30	6-10
3	Axial - Inside Surface	At Weld	Downhill	0.0°	0.234"	0.047"	0.075	5:1	0.625"	1	6-5
4	Axial - Inside Surface	1.0" Below Weld	Downhill	28.6°	0.394"	0.078"	0.125	5:1	0.625"	30	6-3, 6-5
5	Axial Through-Wall	0.4" Below Weld	Uphill	42.6°	--	--	--	--	0.625"	69	6-19

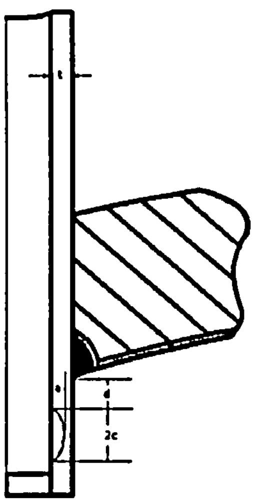
No.	Orientation	Crack Tip Location (d)	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	Source Figure	a/t	Aspect Ratio	Wall Thick. (t)
1	Axial – Inside Surface	1.2" Below Weld	Uphill	30	0.195"	0.078"	28.6°	6-2	0.125	2.5:1	0.625"

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	l
Below Weld (ID)	t	No Limit

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle
30	CRDM	28.6



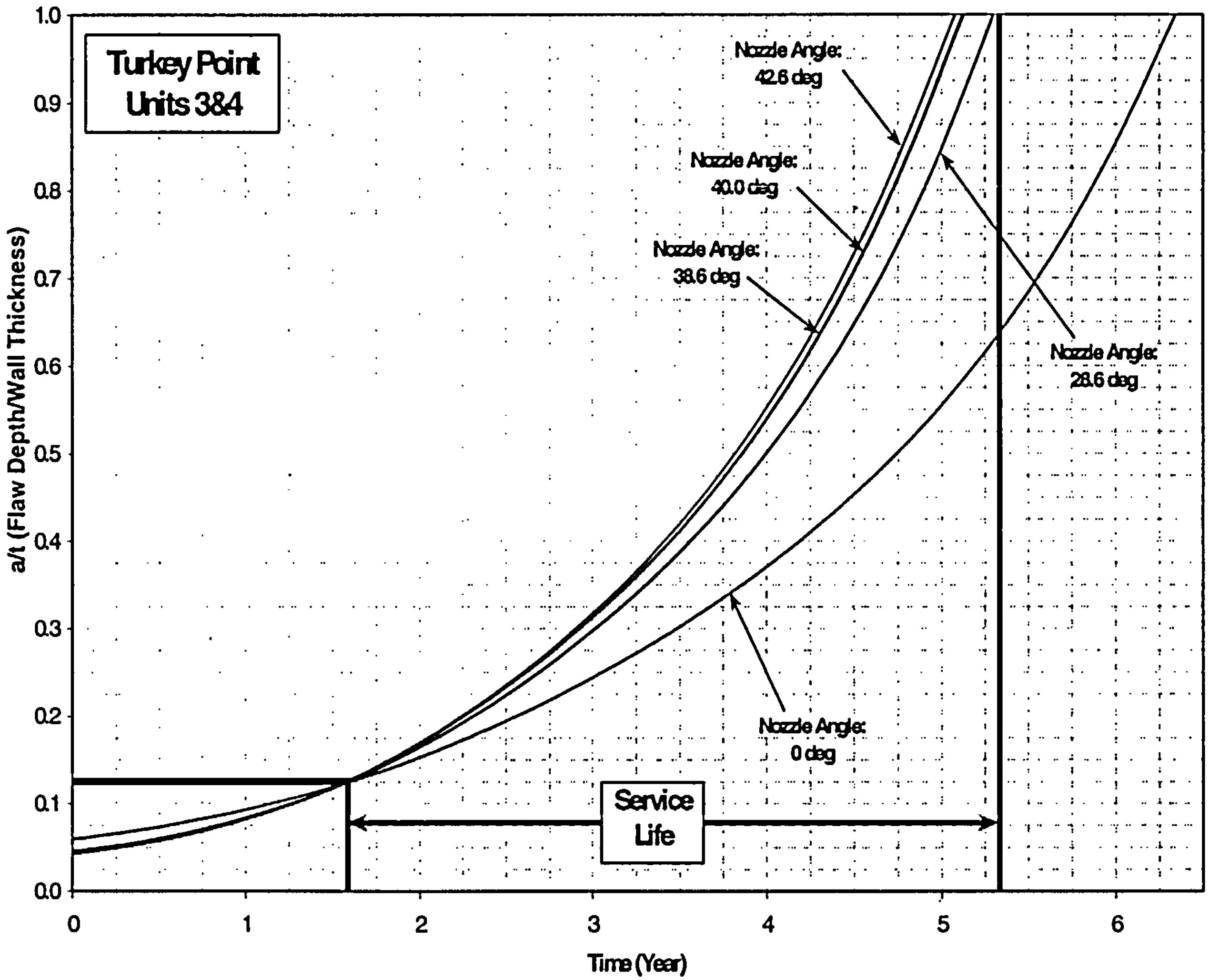


Figure C-1 Example Problem 1

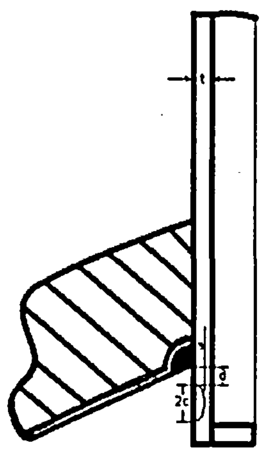
No.	Orientation	Crack Tip Location (d)	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	Source Figure	a/t	Asp. Ratio	Wall Thick. (t)
2	Axial – Outside Surface	1.2" Below Weld	Downhill	30	0.195"	0.078"	28.6°	6-10	0.125	2.5:1	0.625"

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	l
Below Weld (OD)	t	No Limit

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle
30	CRDM	28.6



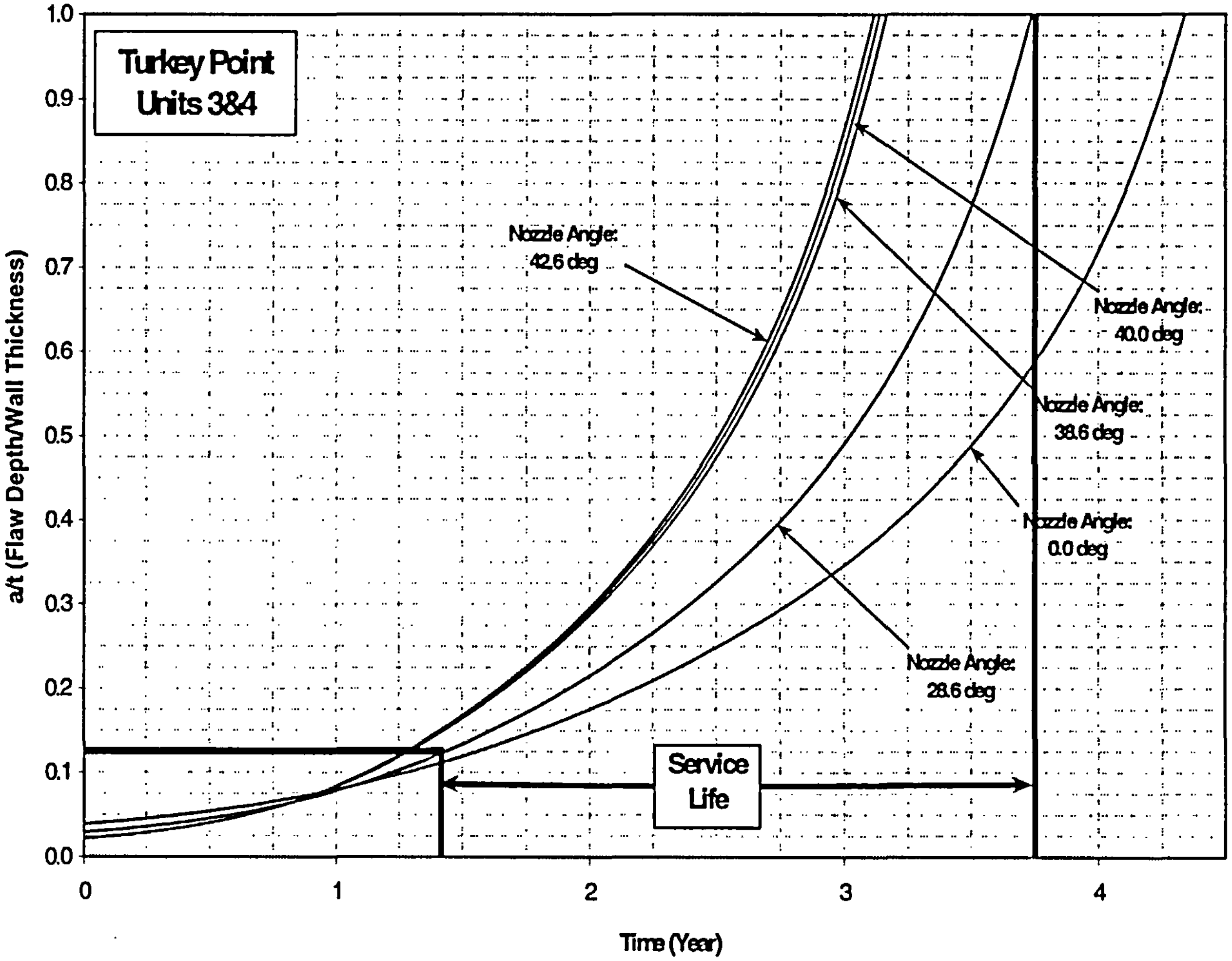


Figure C-2 Example Problem 2

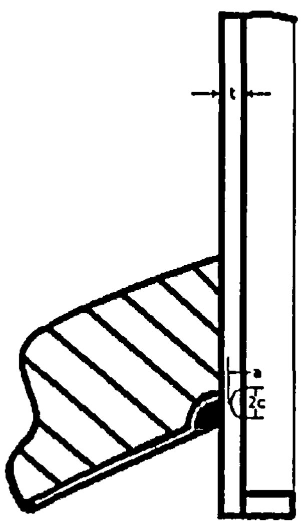
No.	Orientation	Crack Tip Location (d)	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	Source Figure	a/t	Asp. Ratio	Wall Thick. (t)
3	Axial – Inside Surface	At Weld	Downhill	1	0.234"	.047"	0.0°	6-5	0.075	5:1	0.625"

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	l
At and Above Weld (ID)	0.75 t	No Limit

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle
1	CRDM	0.0



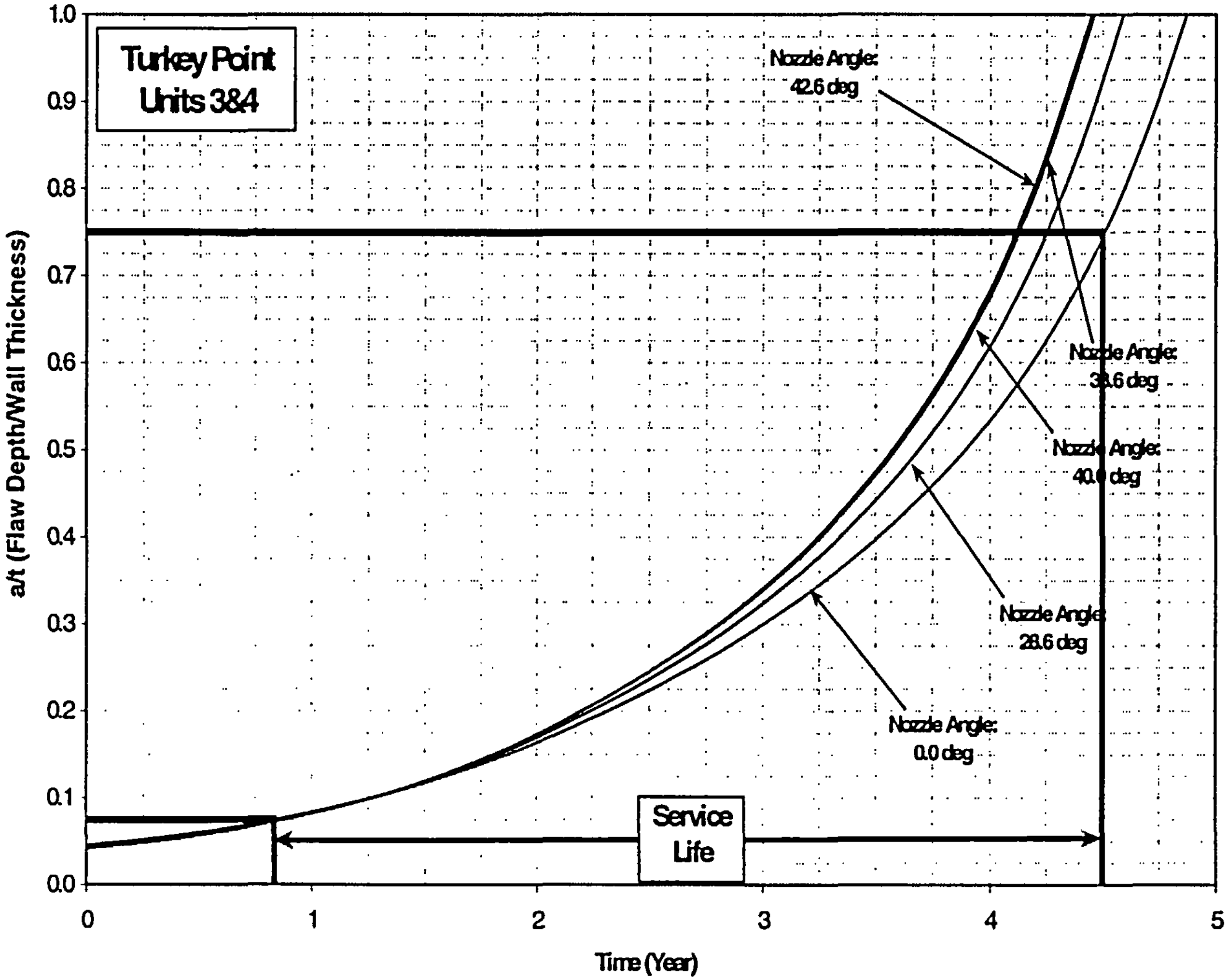


Figure C-3 Example Problem 3

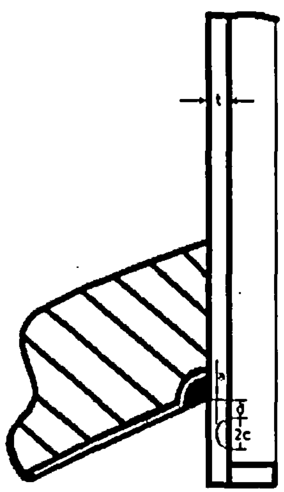
No.	Orientation	Crack Tip Location (d)	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	Source Figure	a/t	Asp. Ratio	Wall Thick. (t)
4a	Axial – Inside Surface	1.0" Below Weld	Downhill	30	0.394"	0.078"	28.6°	6-3	0.125	5:1	0.625"

Acceptance Criteria (Procedure II)

Location	Axial	
	a_f	l
Below Weld (ID)	0.279"	1.39"

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle
30	CRDM	28.6



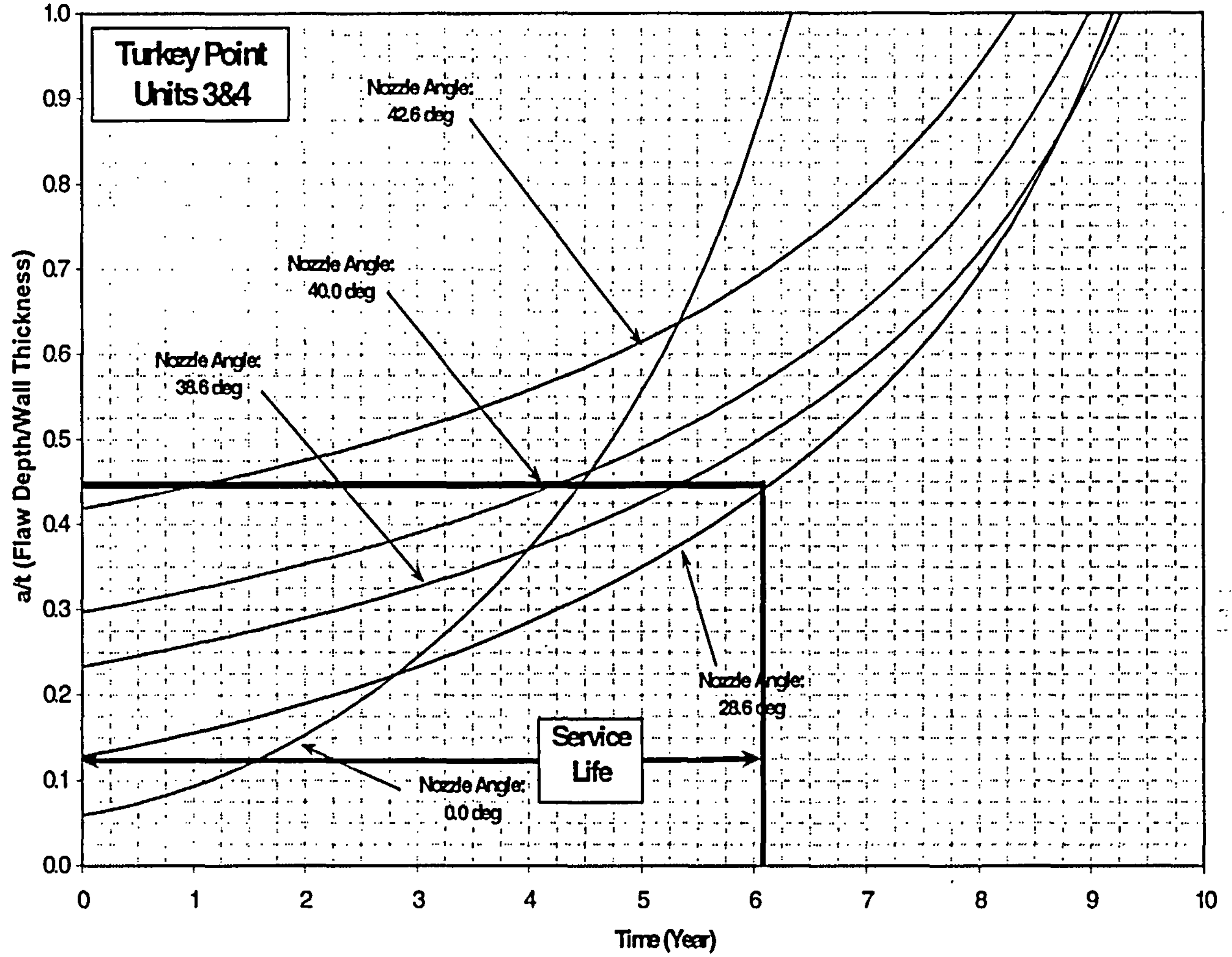


Figure C-4a Example Problem 4 (See also Figure C-4b)

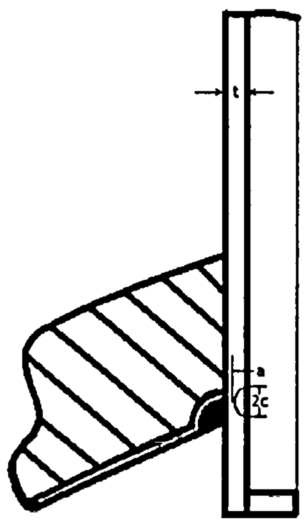
No.	Orientation	Crack Tip Location (d)	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	Source Figure	a/t	Asp. Ratio	Wall Thick. (t)
4b	Axial – Inside Surface	At Weld	Downhill	30	1.39"	0.279"	28.6°	6-5	0.45	5:1	0.625"

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	l
At Weld (ID)	0.75 t	No Limit

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle
30	CRDM	28.6



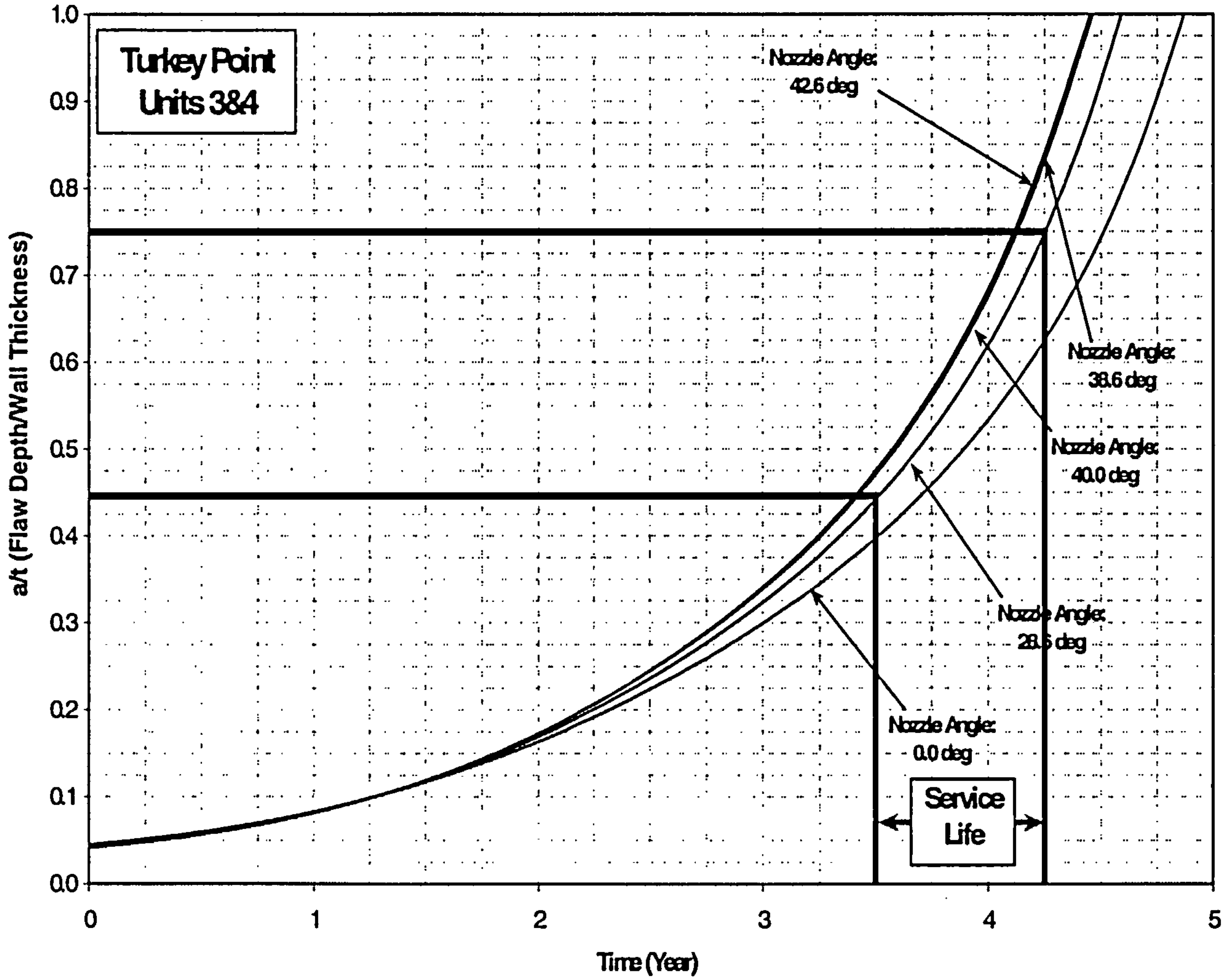


Figure C-4b Example Problem 4 (See also Figure C-4a)

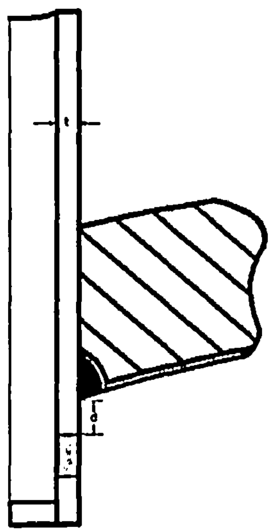
No.	Orientation	Crack Tip Location (d)	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	Source Figure	a/t	Asp. Ratio	Wall Thick. (t)
5	Axial – Through Wall	0.4" Below Weld	Uphill	69	--	--	42.6°	6-19	--	--	0.625"

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	l
Below Weld (ID)	t	Bottom Weld

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle
69	CRDM	42.6



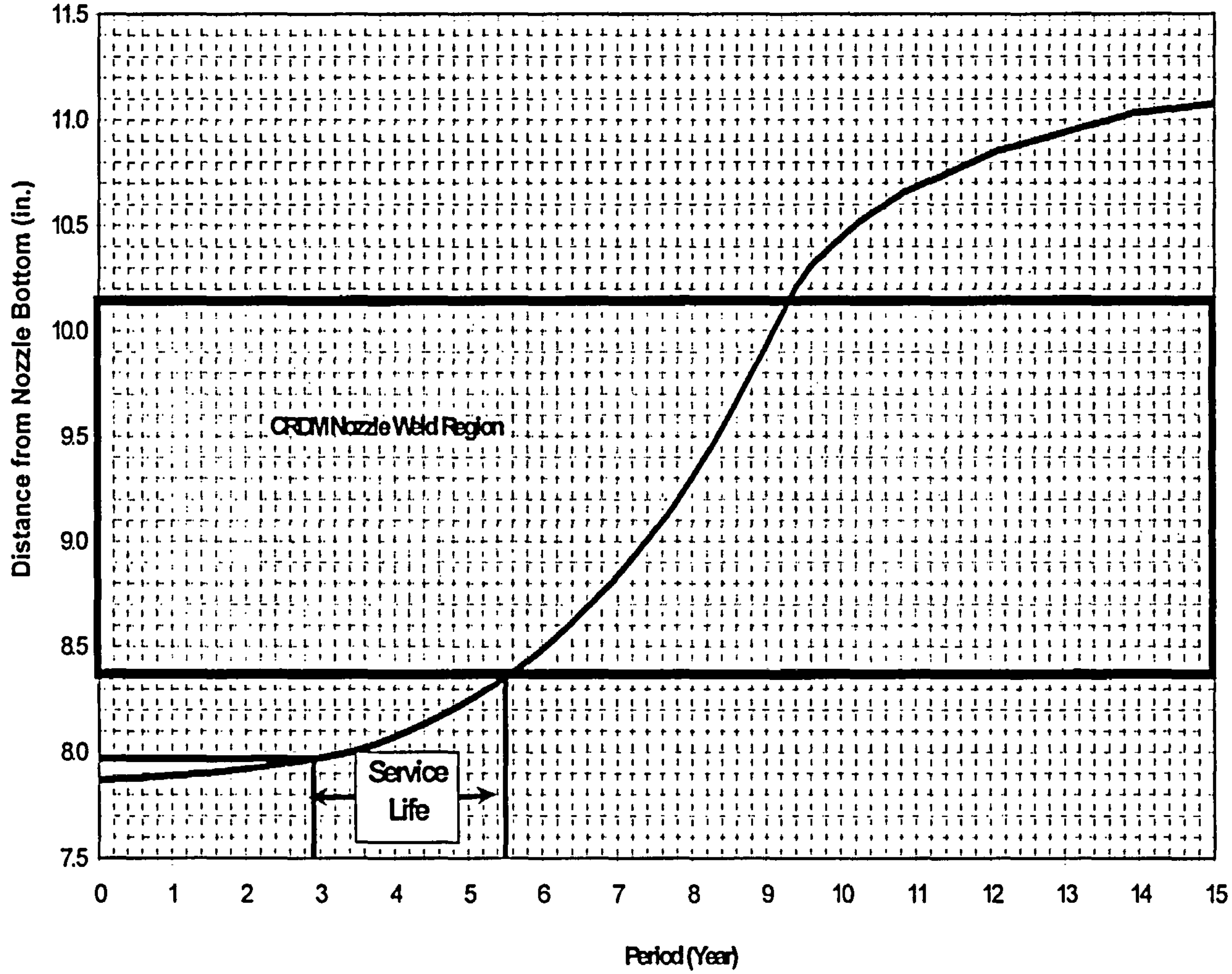


Figure C-5 Example Problem 5

APPENDIX D

WORKSHEETS

Table D-1 Turkey Point Units 3&4 Head Penetration Nozzles with the Intersection Angles Identified

Nozzle No.	Type	Angle (Degrees)	Nozzle No.	Type	Angle (Degrees)	Nozzle No.	Type	Angle (Degrees)
1	CRDM	0.0	23	CRDM	25.4	45	CRDM	33.1
2	CRDM	8.7	24	CRDM	25.4	46	CRDM	37.3
3	CRDM	8.7	25	CRDM	25.4	47	CRDM	37.3
4	CRDM	8.7	26	CRDM	27.0	48	CRDM	37.3
5	CRDM	8.7	27	CRDM	27.0	49	CRDM	37.3
6	CRDM	12.4	28	CRDM	27.0	51	CRDM	38.6
7	CRDM	12.4	29	CRDM	27.0	53	CRDM	38.6
8	CRDM	12.4	30	CRDM	28.6	55	CRDM	38.6
9	CRDM	12.4	31	CRDM	28.6	57	CRDM	38.6
10	CRDM	17.6	32	CRDM	28.6	58	CRDM	40.0
11	CRDM	17.6	33	CRDM	28.6	59	CRDM	40.0
12	CRDM	17.6	34	CRDM	28.6	60	CRDM	40.0
13	CRDM	17.6	35	CRDM	28.6	61	CRDM	40.0
14	CRDM	19.8	36	CRDM	28.6	62	CRDM	42.6
15	CRDM	19.8	37	CRDM	28.6	63	CRDM	42.6
16	CRDM	19.8	38	CRDM	33.1	64	CRDM	42.6
17	CRDM	19.8	39	CRDM	33.1	65	CRDM	42.6
18	CRDM	19.8	40	CRDM	33.1	66	CRDM	42.6
19	CRDM	19.8	41	CRDM	33.1	67	CRDM	42.6
20	CRDM	19.8	42	CRDM	33.1	68	CRDM	42.6
21	CRDM	19.8	43	CRDM	33.1	69	CRDM	42.6
22	CRDM	25.4	44	CRDM	33.1			

Table D-2 Summary of R.V. Head Penetration Flaw Acceptance Criteria (Limits for Future Growth)

Location	Axial		Circumferential	
	a_f	ℓ	a_f	ℓ
Below Weld (ID)	t	no limit	t	.75 circ.
At and Above Weld (ID)	0.75 t	no limit	*	*
Below Weld (OD)	t	no limit	t	.75 circ.
Above Weld (OD)	*	*	*	*

Note: Surface flaws of any size in the attachment weld are not acceptable.

* Requires case-by-case evaluation and discussion with regulatory authority.

a_f = Flaw Depth
ℓ = Flaw Length
t = Wall Thickness

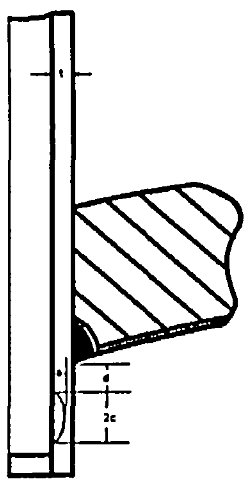
Orientation	Crack Tip Location (d)	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Inside Surface	______ " Below Weld	Uphill							

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	l

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



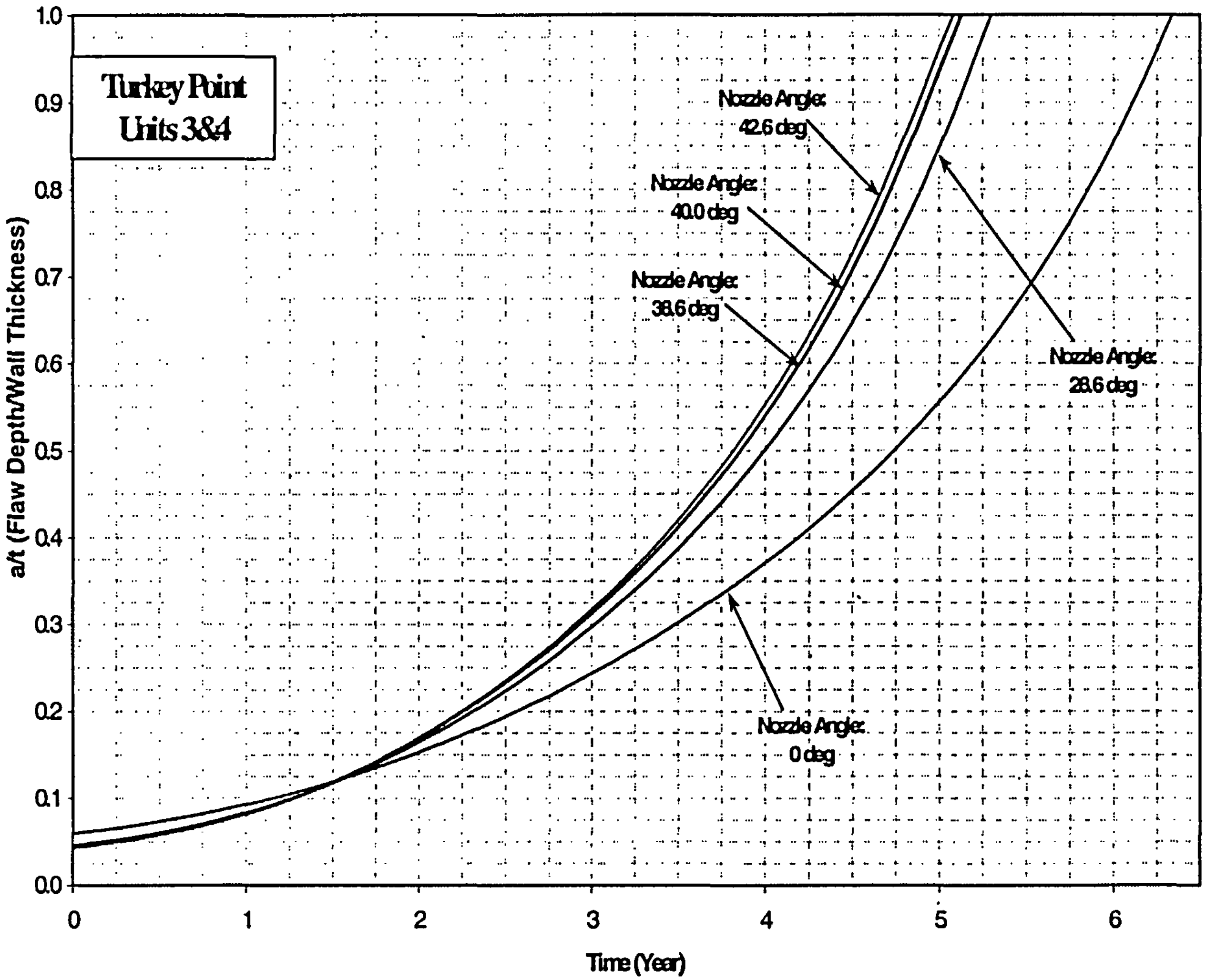


Figure D-1 Inside, Axial Surface Flaws, .5" Below the Attachment Weld, Nozzle Uphill Side - Crack Growth Predictions

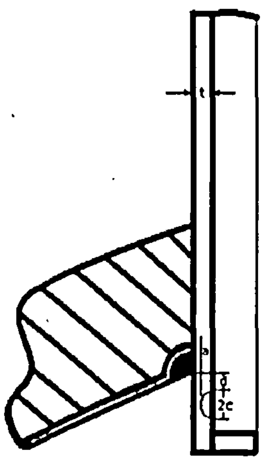
Orientation	Crack Tip Location (d)	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Inside Surface	_____ " Below Weld	Downhill							

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	l

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



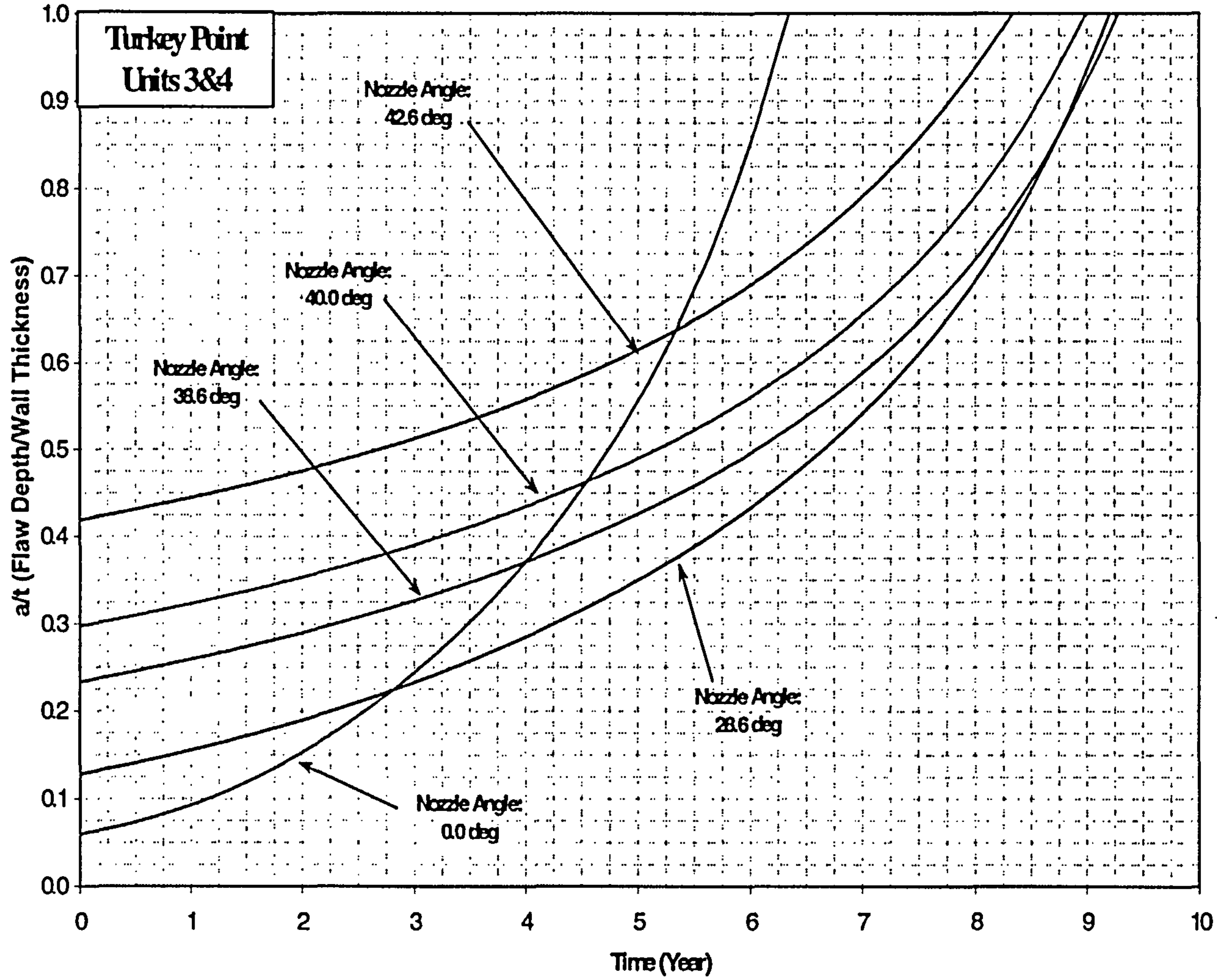


Figure D-2 Inside, Axial Surface Flaws, .5" Below the Attachment Weld, Nozzle Downhill Side - Crack Growth Predictions

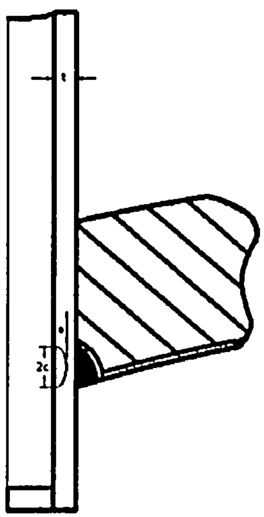
Orientation	Crack Tip Location (d)	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Inside Surface	At Weld	Uphill							

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	l

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



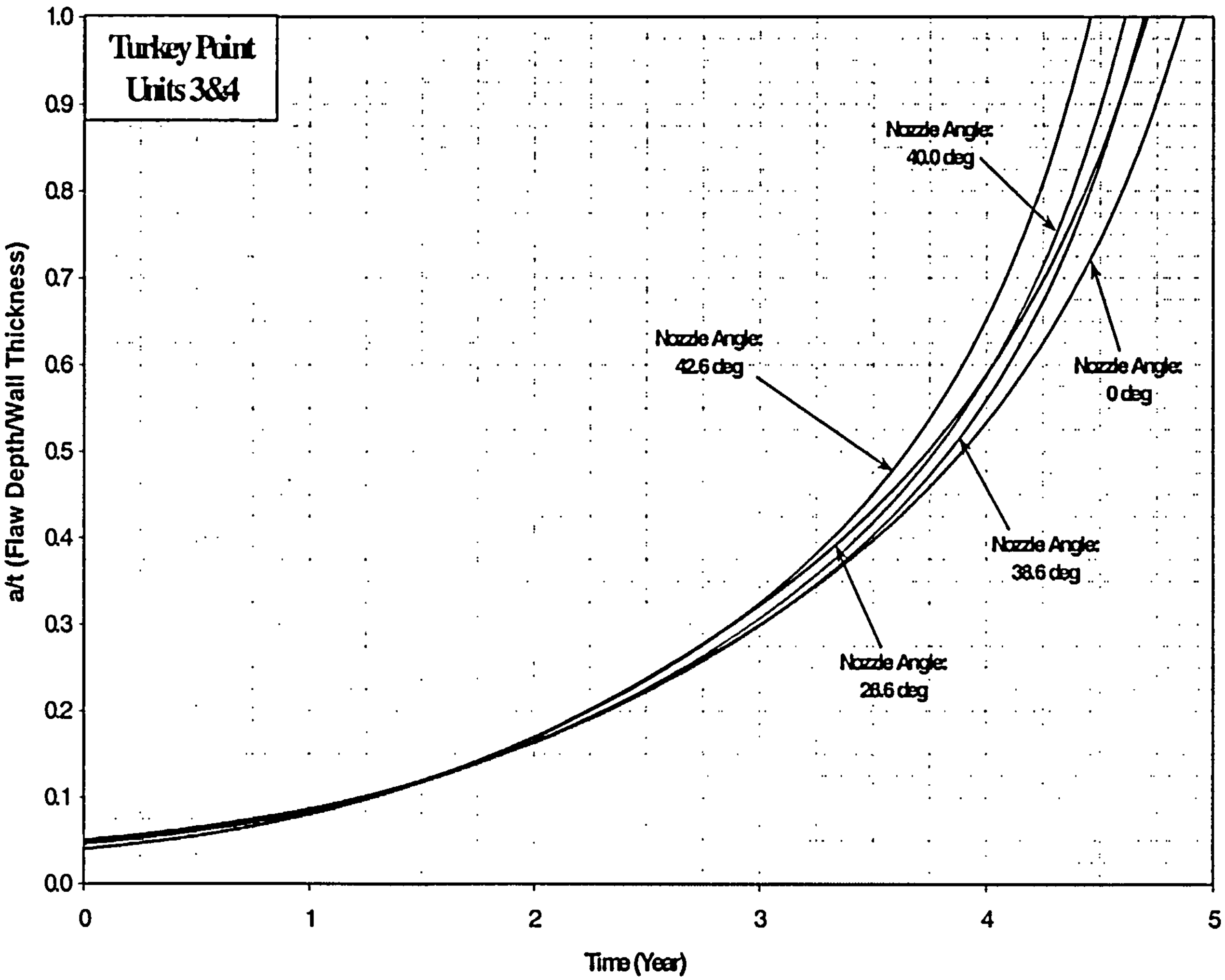


Figure D-3 Inside, Axial Surface Flaws, At the Attachment Weld, Nozzle Uphill Side - Crack Growth Predictions

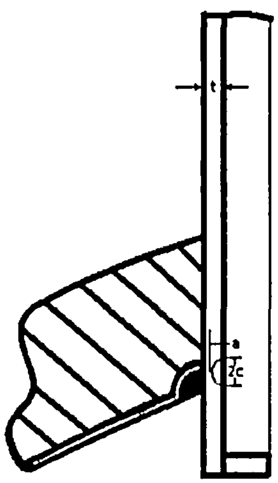
Orientation	Crack Tip Location (d)	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Inside Surface	At Weld	Downhill							

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	l

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



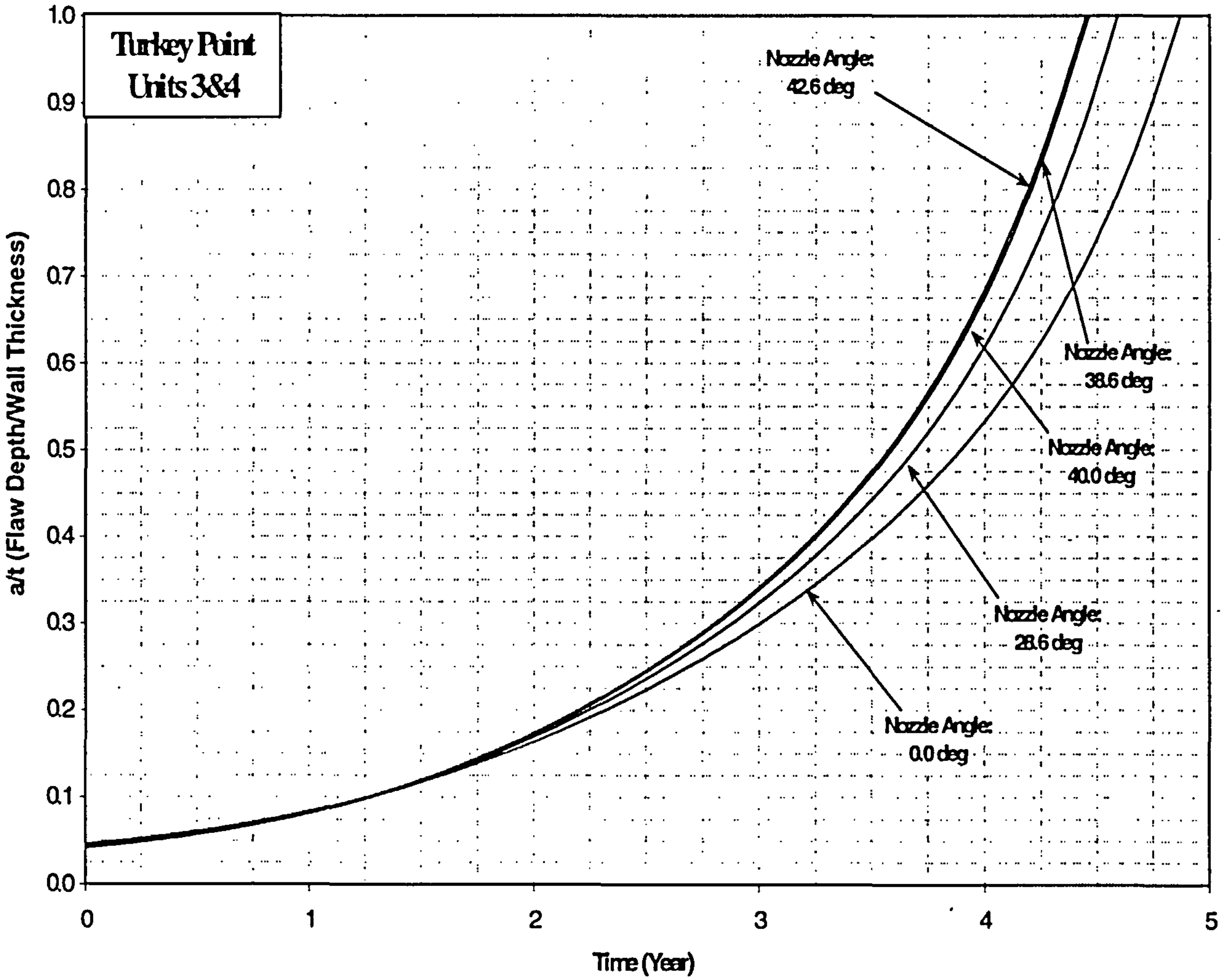


Figure D-4 Inside, Axial Surface Flaws, At the Attachment Weld, Nozzle Downhill Side - Crack Growth Predictions

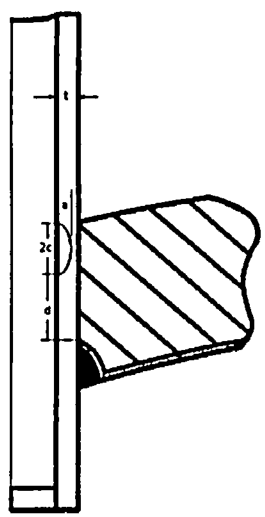
Orientation	Crack Tip Location (d)	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Inside Surface	______" Above Weld	Uphill							

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	l

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



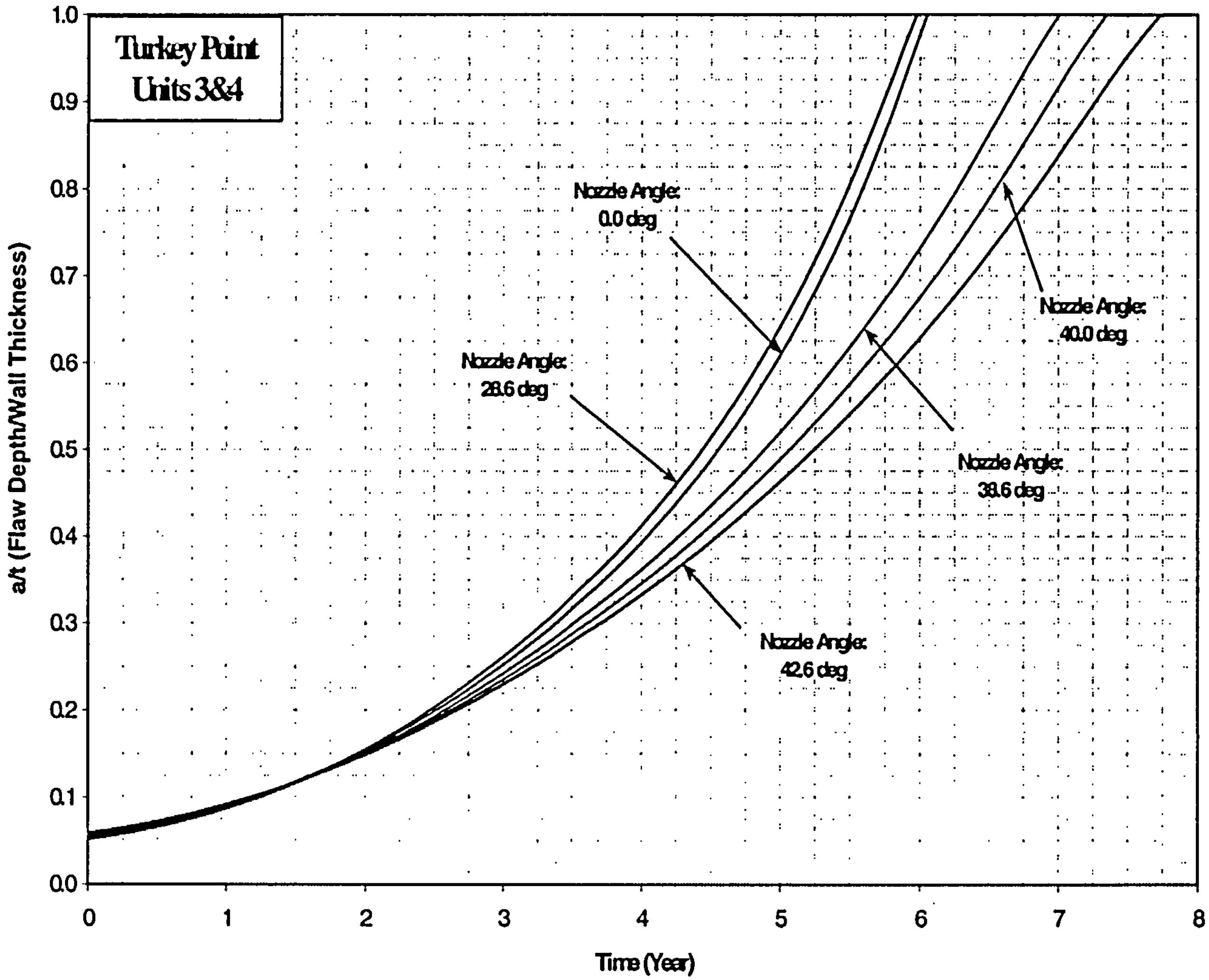


Figure D-5 Inside, Axial Surface Flaws, .5" Above the Attachment Weld, Nozzle Uphill Side - Crack Growth Predictions

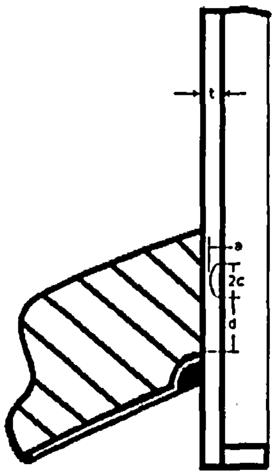
Orientation	Crack Tip Location (d)	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Inside Surface	______" Above Weld	Downhill							

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	l

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



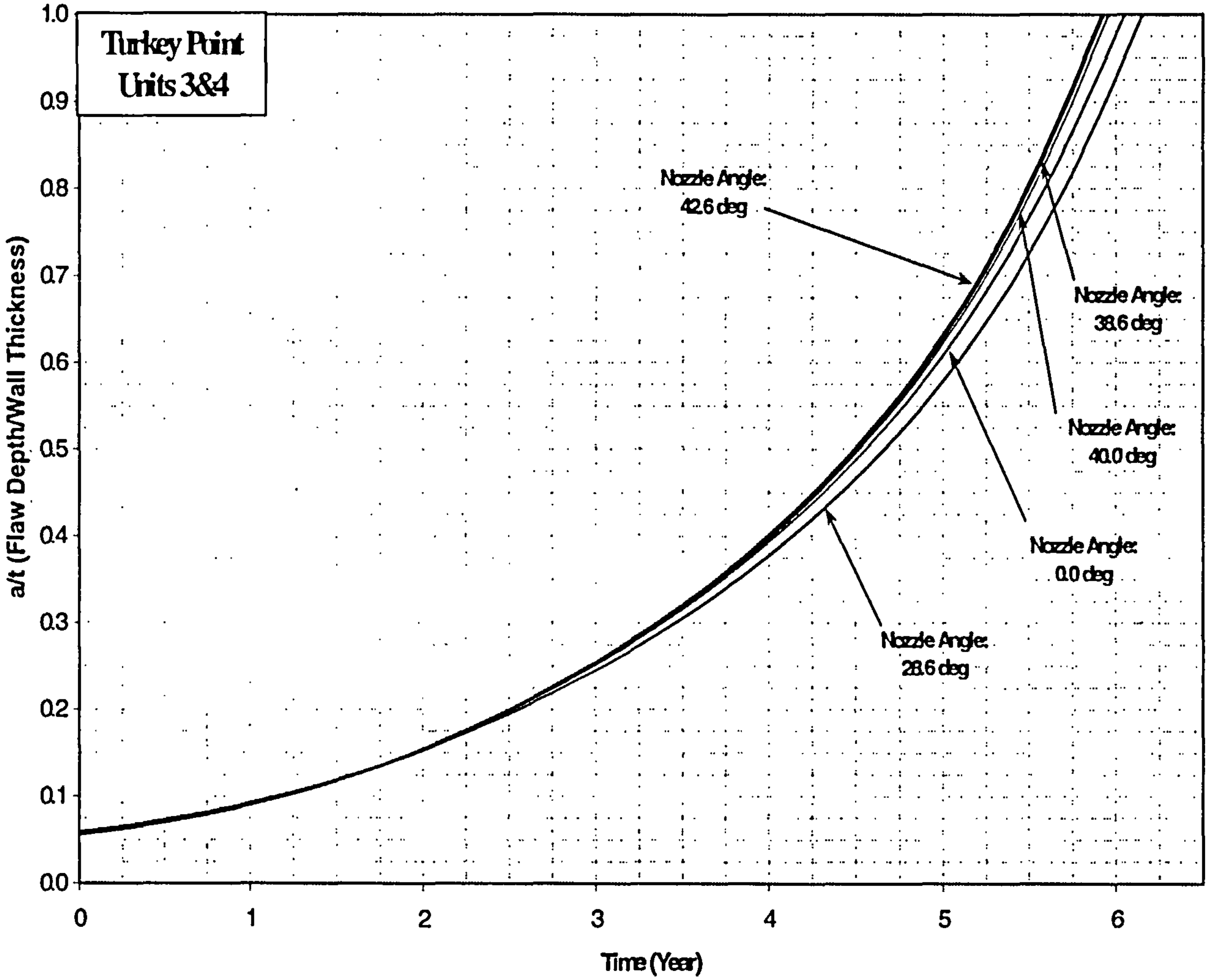


Figure D-6 Inside, Axial Surface Flaws, .5" Above the Attachment Weld, Nozzle Downhill Side - Crack Growth Predictions

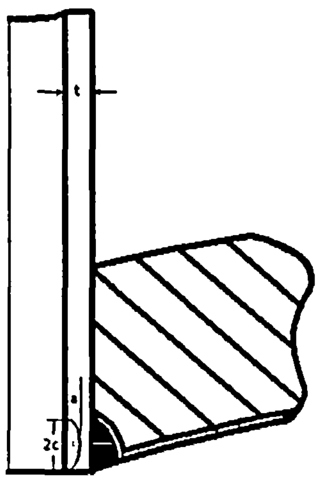
Orientation	Crack Tip Location (d)	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Inside Surface	At Weld	Uphill / Downhill	Head Vent						

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	l

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



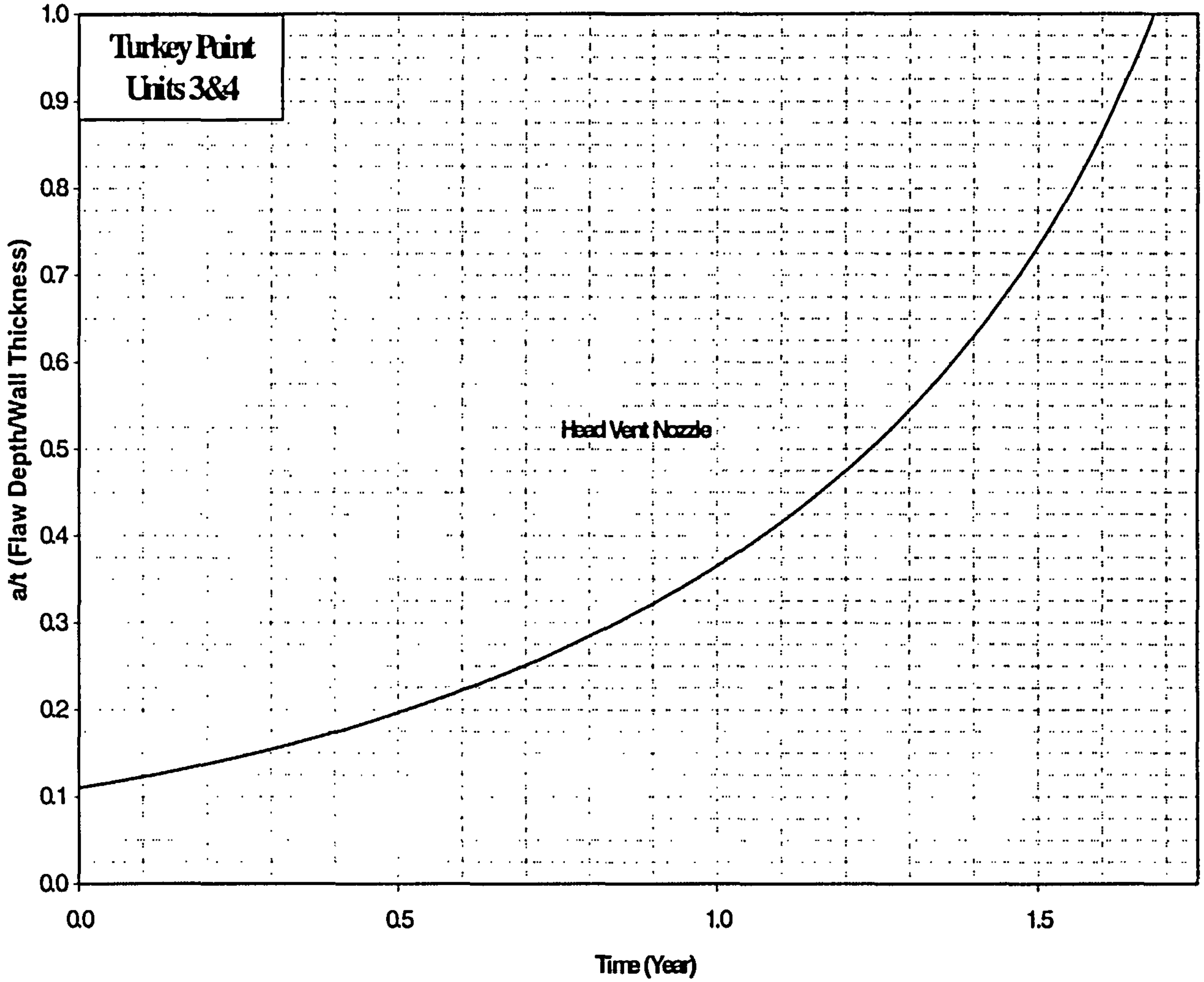


Figure D-7 Inside, Axial Surface Flaws, At the Attachment Weld, Head Vent, Nozzle Downhill Side - Crack Growth Predictions

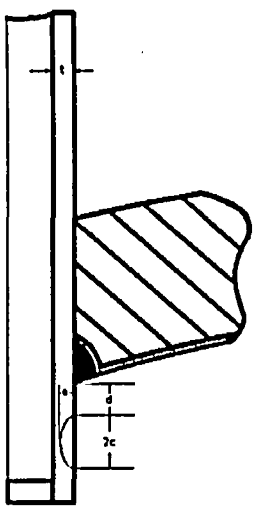
Orientation	Crack Tip Location (d)	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Outside Surface	______" Below Weld	Uphill							

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	l

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



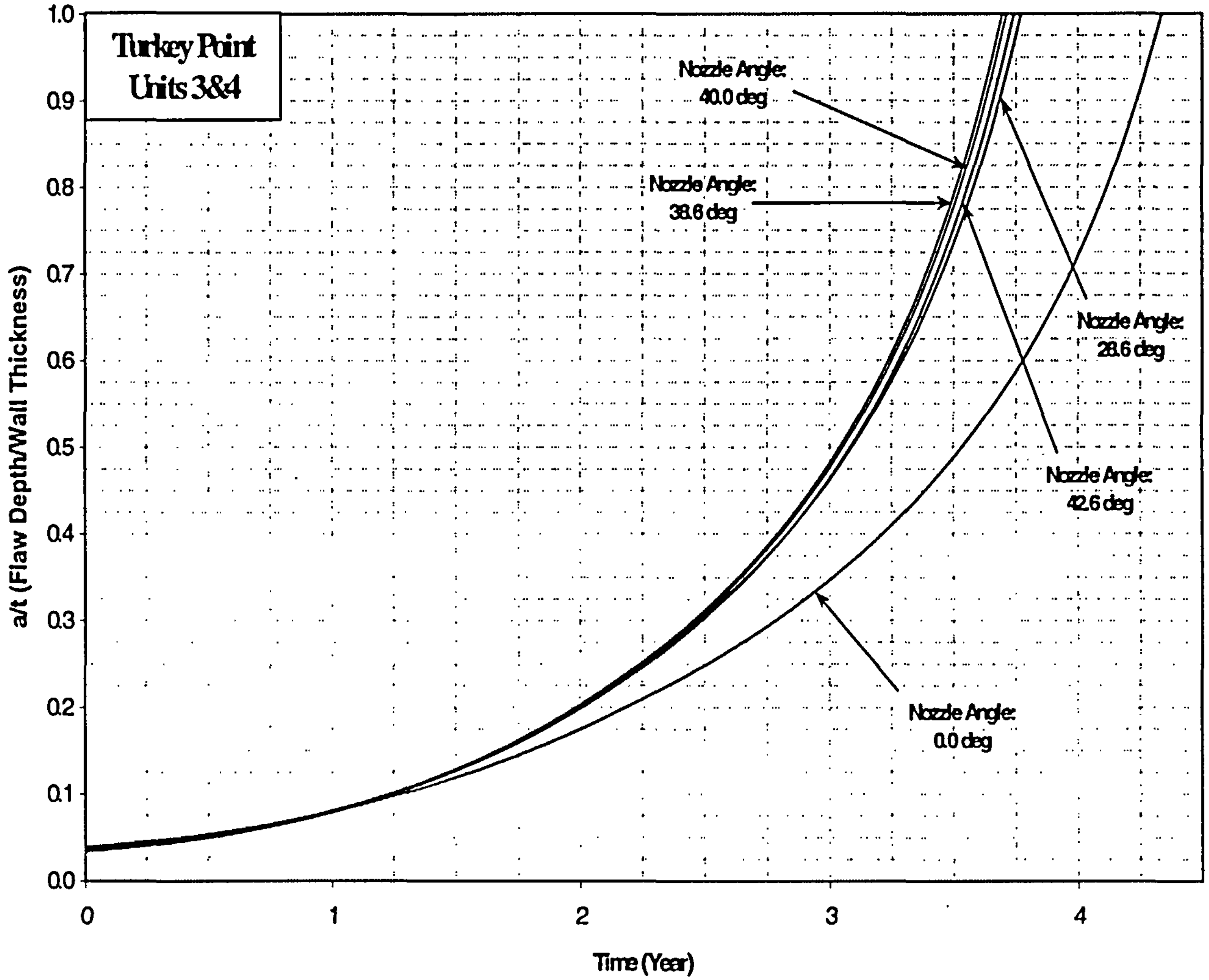


Figure D-8 Outside, Axial Surface Flaws, Below the Attachment Weld, Nozzle Uphill Side - Crack Growth Predictions

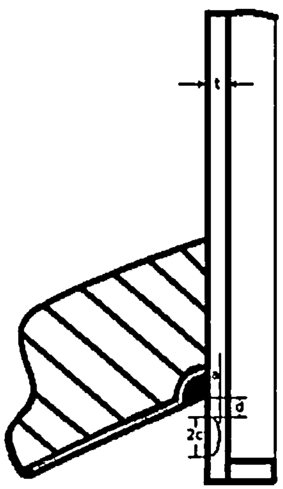
Orientation	Crack Tip Location (d)	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Outside Surface	______ " Below Weld	Downhill							

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	l

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



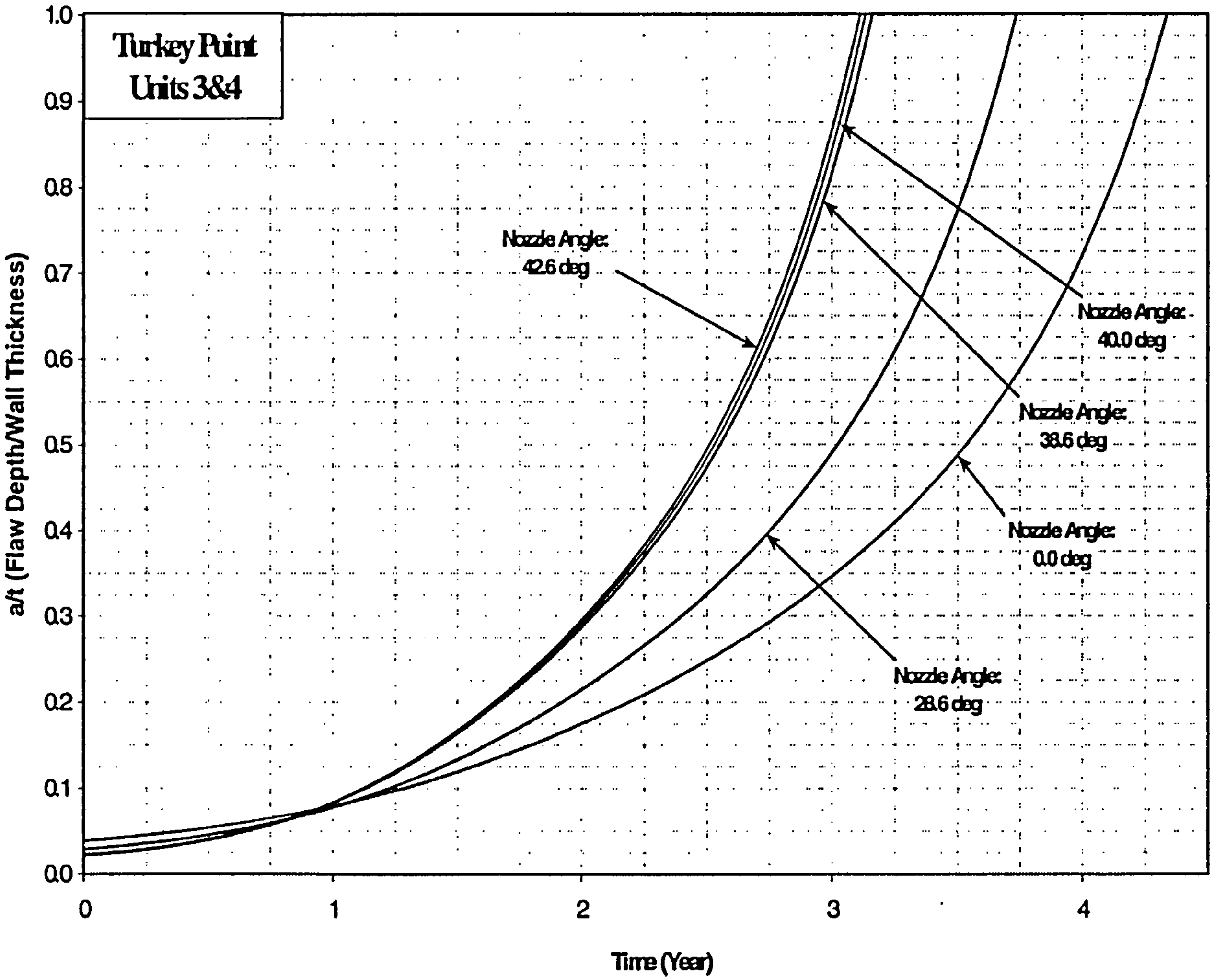


Figure D-9 Outside, Axial Surface Flaws, Below the Attachment Weld, Nozzle Downhill Side - Crack Growth Predictions

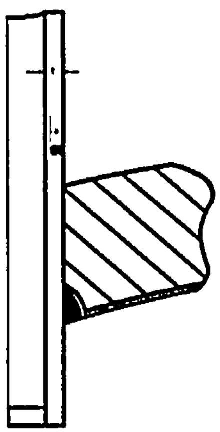
Orientation	Crack Tip Location (d)	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Circum. – Outside Surface	______" Above Weld	N/A							

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	l

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



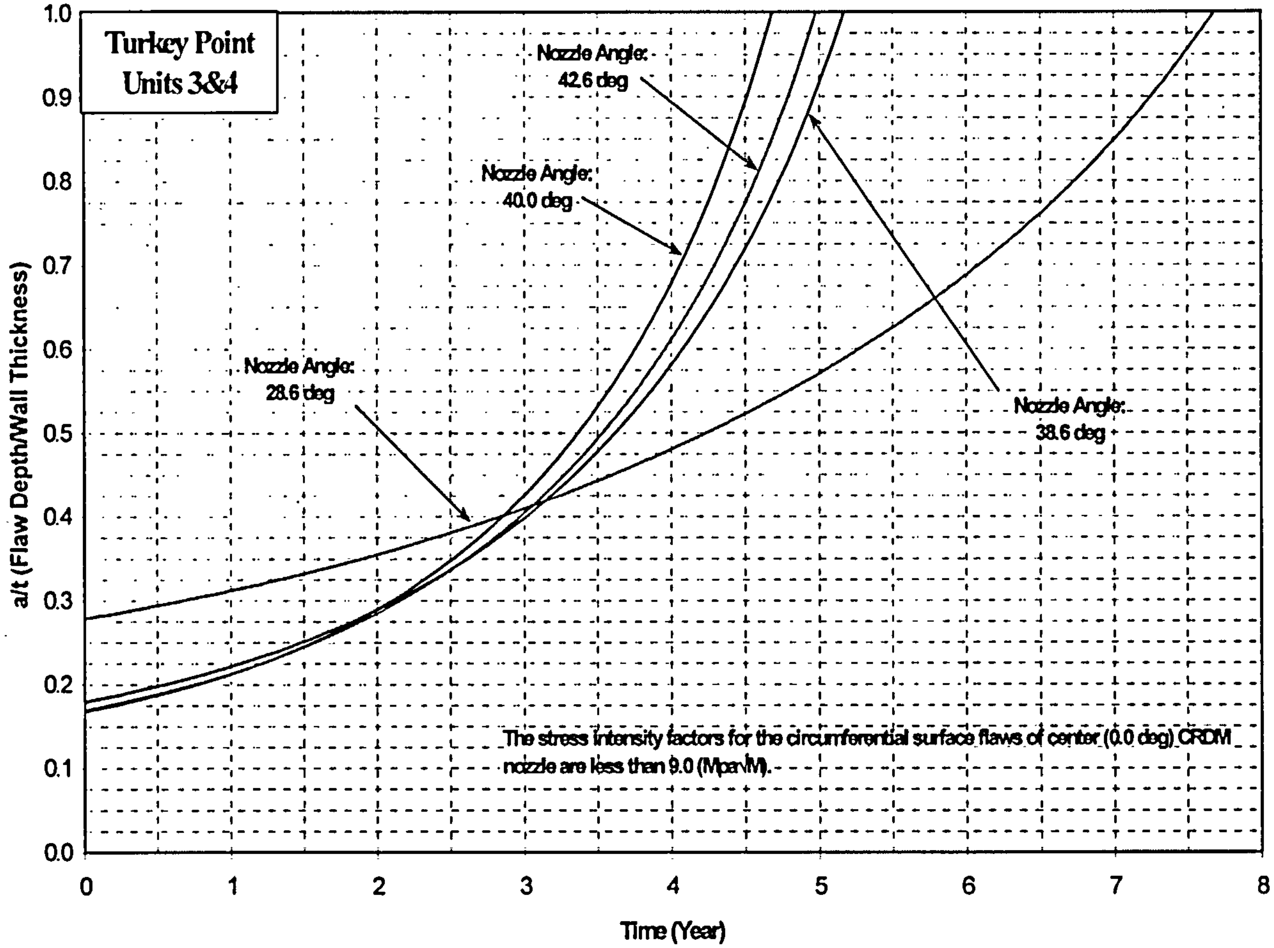


Figure D-10 Outside, Circumferential Surface Flaws, Along the Top of the Attachment Weld - Crack Growth Predictions (MRP Factor of 2.0 Included)

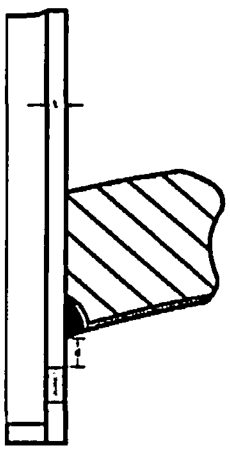
Orientation	Crack Tip Location (d)	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Through Wall	______ " Below Weld	Uphill / Downhill	0.0°						

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	l

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



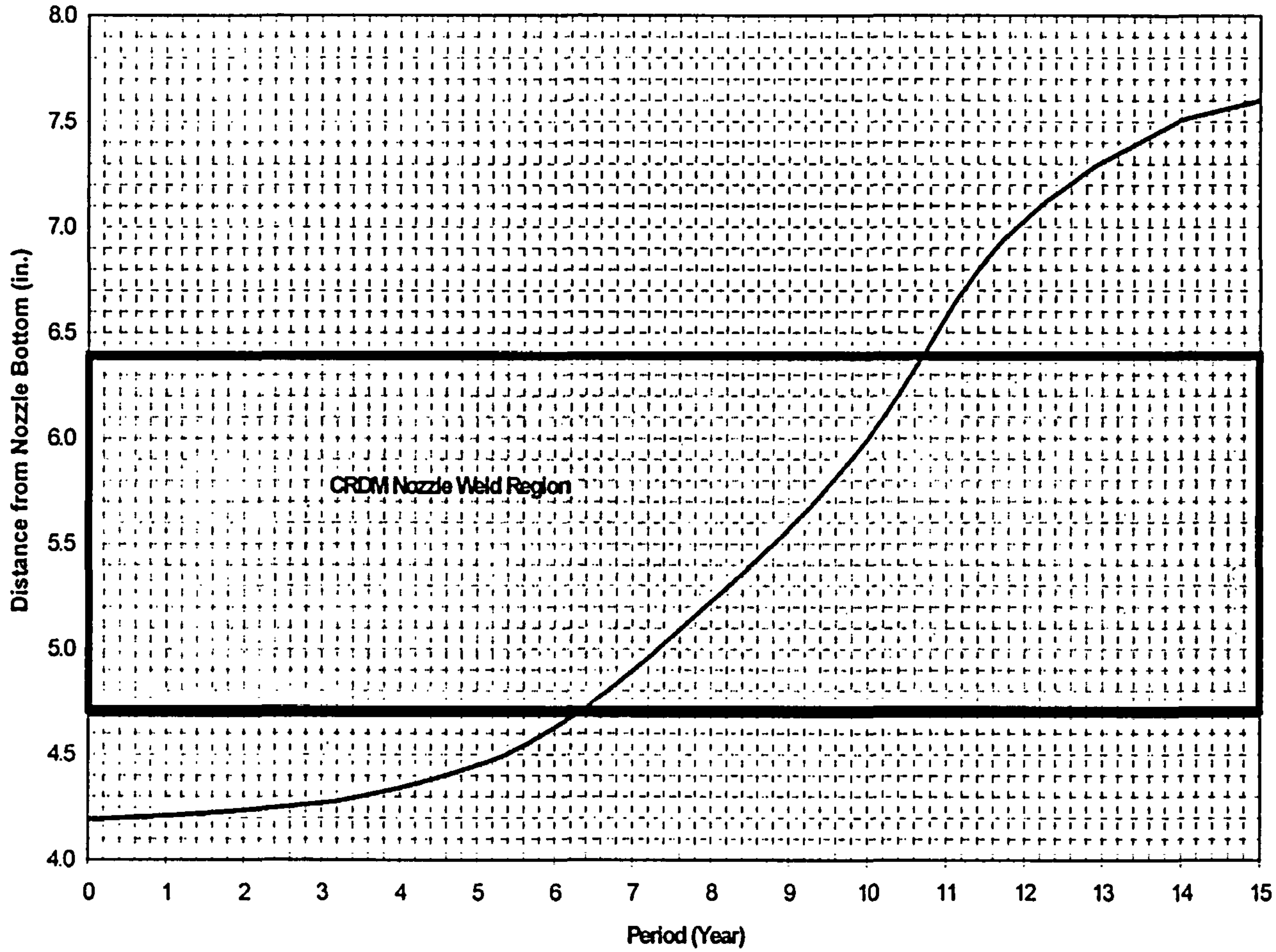


Figure D-11 Through-Wall Axial Flaws Located in the Center CRDM (0.0 Degrees) Penetration, Uphill and Downhill Side - Crack Growth Predictions

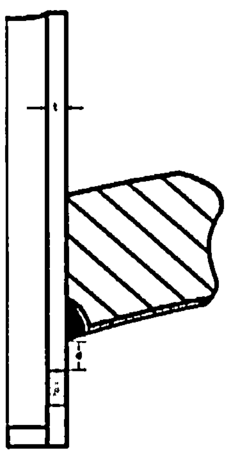
Orientation	Crack Tip Location (d)	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Through Wall	______ " Below Weld	Uphill	28.6°						

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	l

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



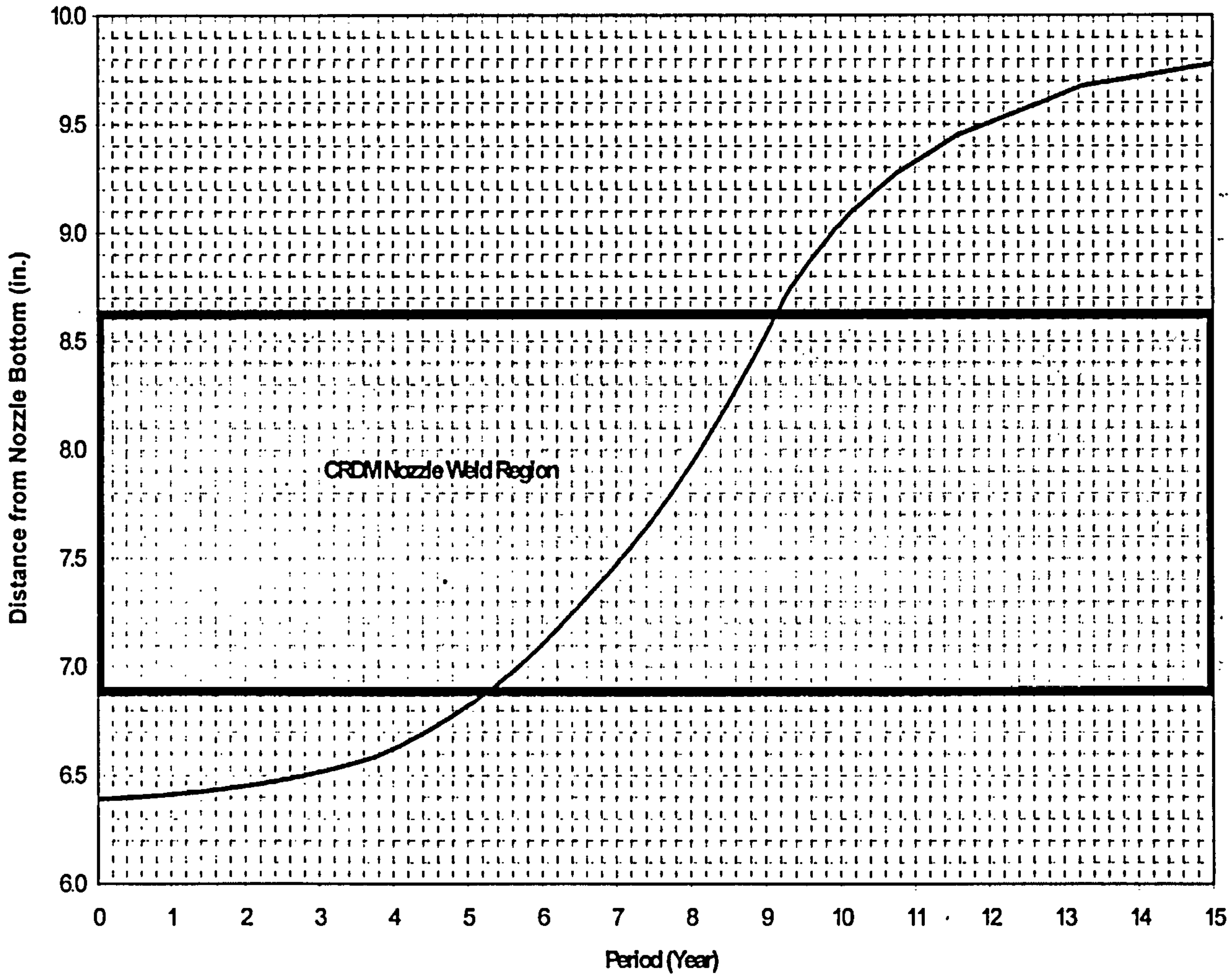


Figure D-12 Through-Wall Axial Flaws Located in the 28.6 Degree Row of Penetrations, Uphill Side - Crack Growth Predictions

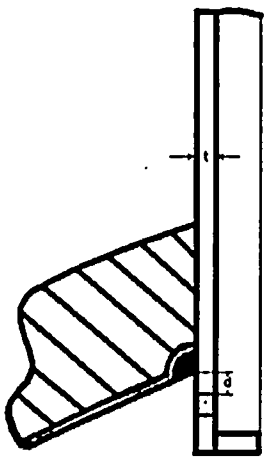
Orientation	Crack Tip Location (d)	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Through Wall	______" Below Weld	Downhill	28.6°						

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	l

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



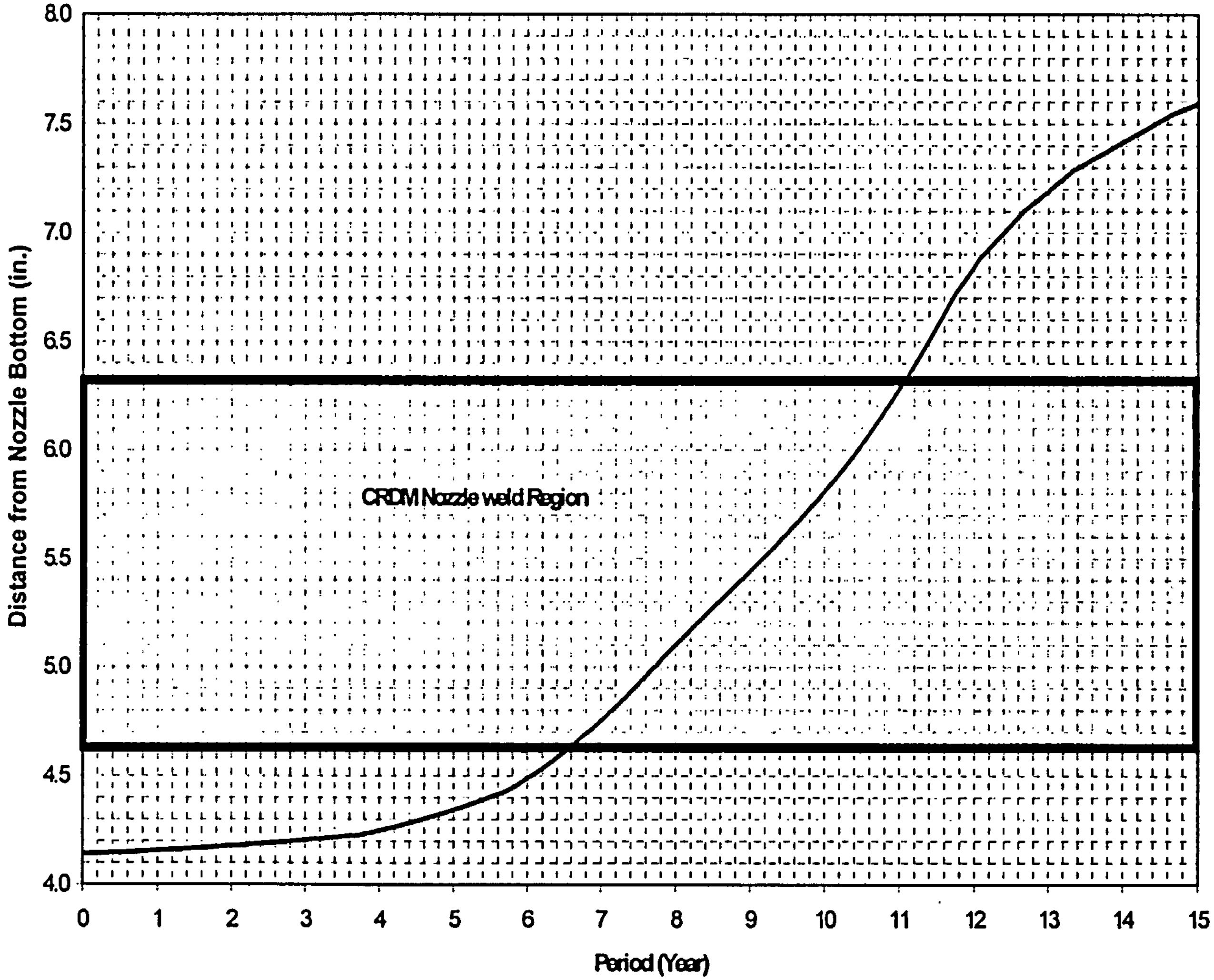


Figure D-13 Through-Wall Axial Flaws Located in the 28.6 Degree Row of Penetrations, Downhill Side - Crack Growth Predictions

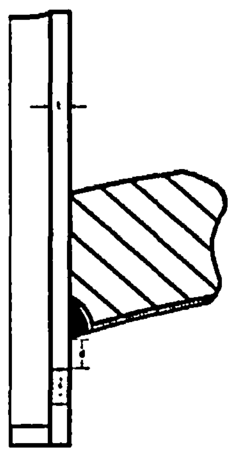
Orientation	Crack Tip Location (d)	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Through Wall	______ " Below Weld	Uphill	38.6°						

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	l

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



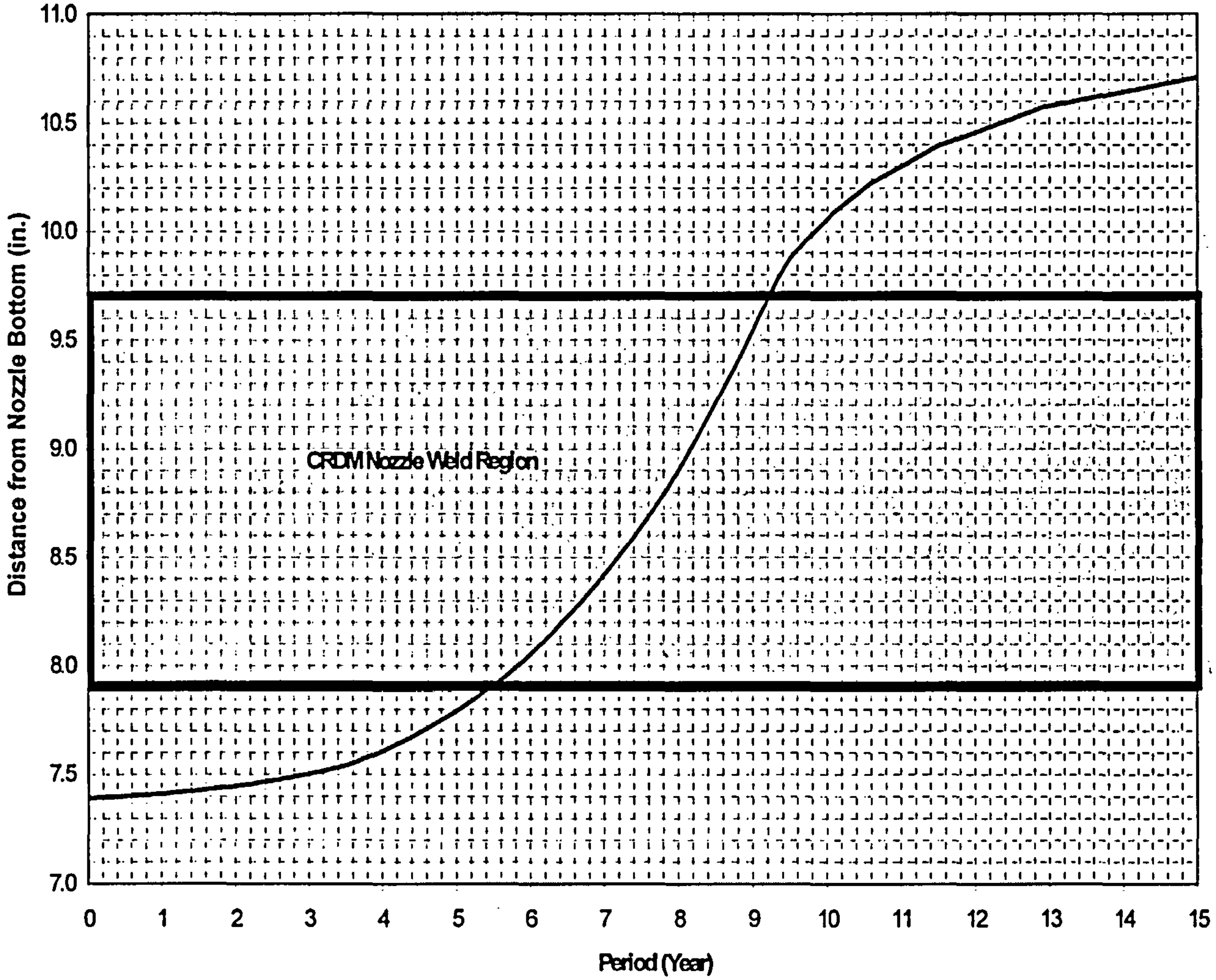


Figure D-14 Through-Wall Axial Flaws Located in the 38.6 Degree Row of Penetrations, Uphill Side - Crack Growth Predictions

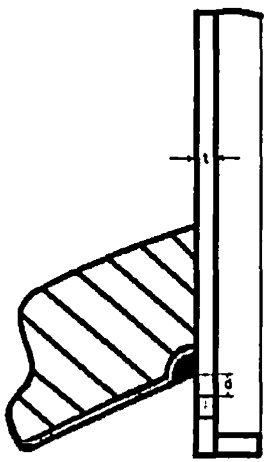
Orientation	Crack Tip Location (d)	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Through Wall	______ " Below Weld	Downhill	38.6°						

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	l

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



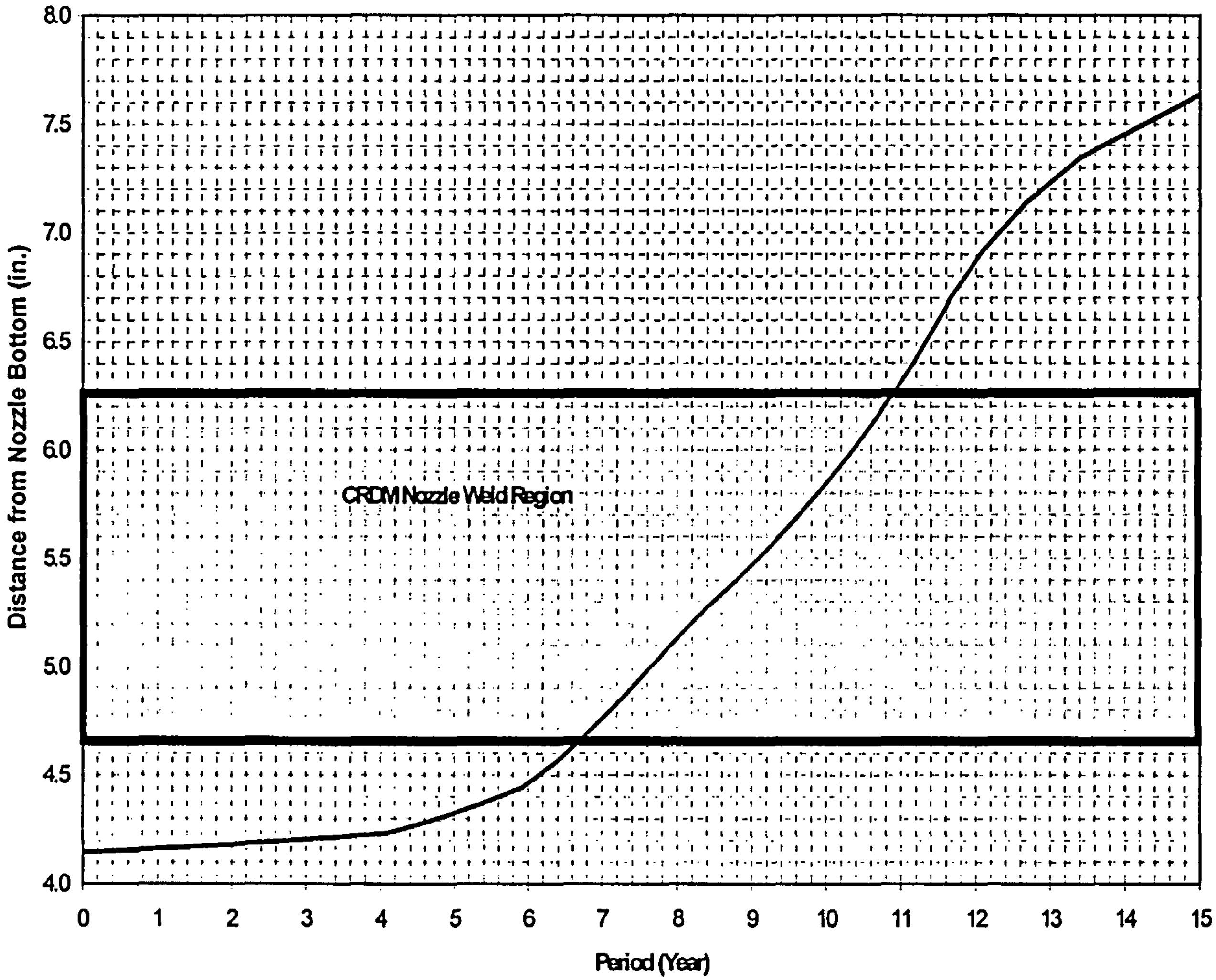


Figure D-15 Through-Wall Axial Flaws Located in the 38.6 Degree Row of Penetrations, Downhill Side - Crack Growth Predictions

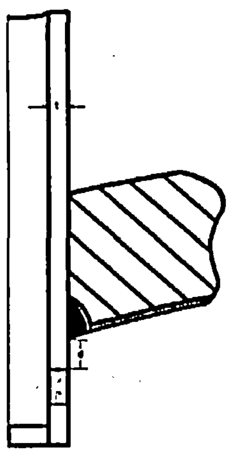
Orientation	Crack Tip Location (d)	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Through Wall	______" Below Weld	Uphill	40.0°						

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	l

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



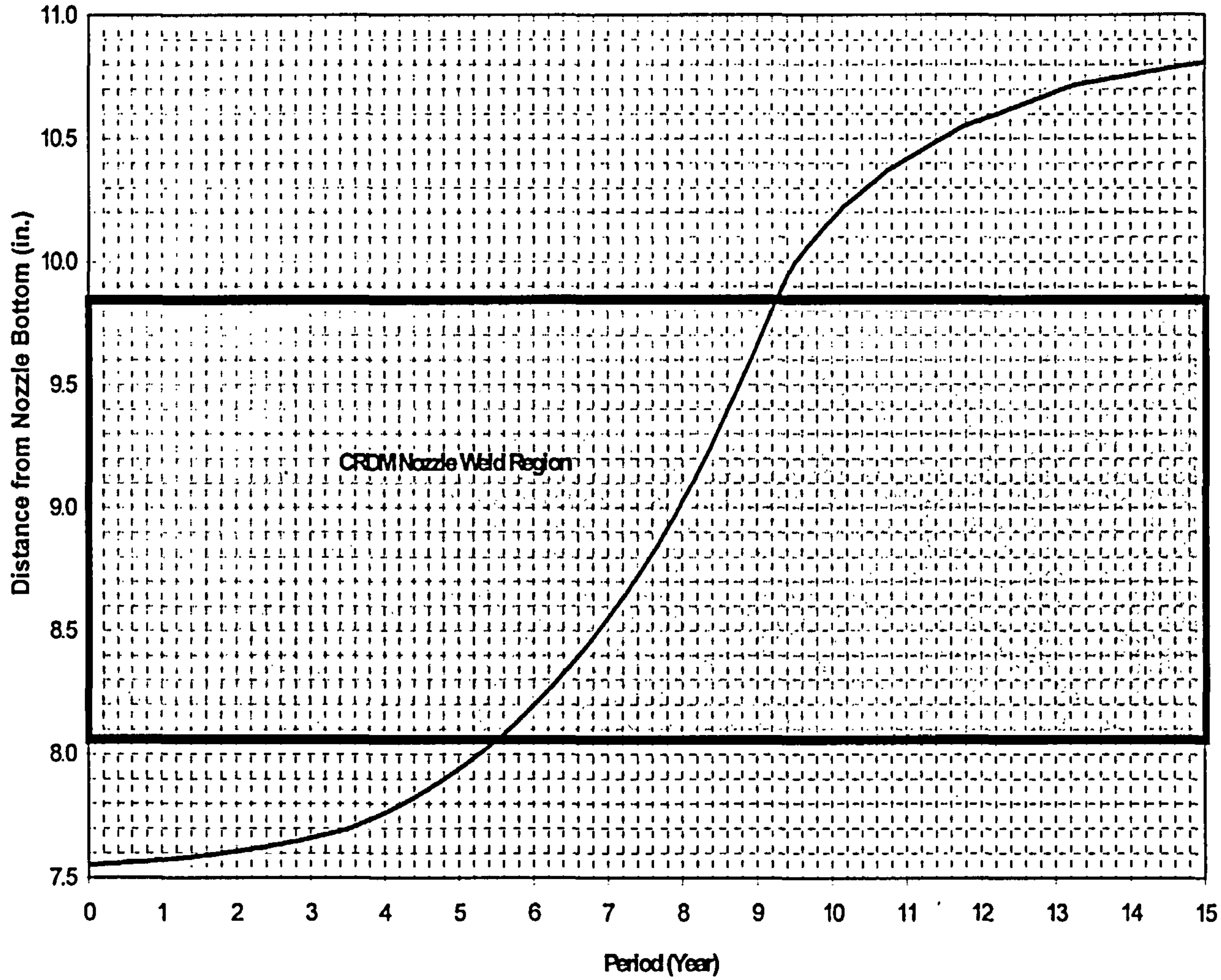


Figure D-16 Through-Wall Axial Flaws Located in the 40.0 Degree Row of Penetrations, Uphill Side - Crack Growth Predictions

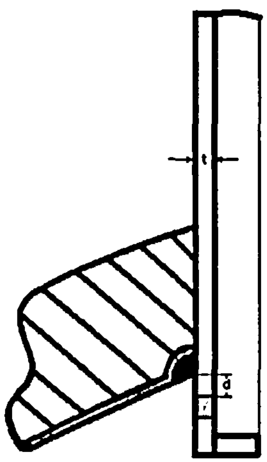
Orientation	Crack Tip Location (d)	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Through Wall	______" Below Weld	Downhill	40.0°						

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	l

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



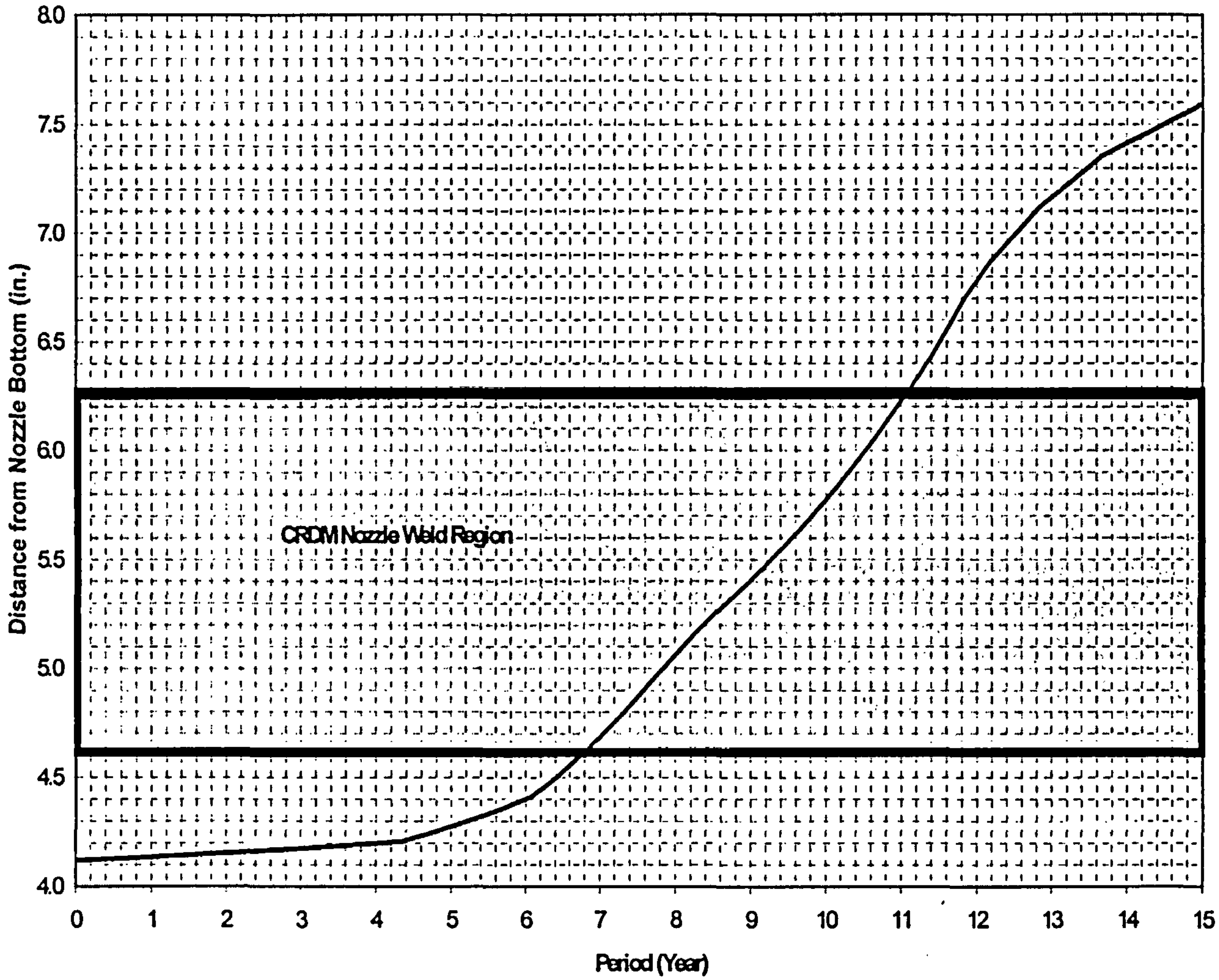


Figure D-17 Through-Wall Axial Flaws Located in the 40.0 Degree Row of Penetrations, Downhill Side - Crack Growth Predictions

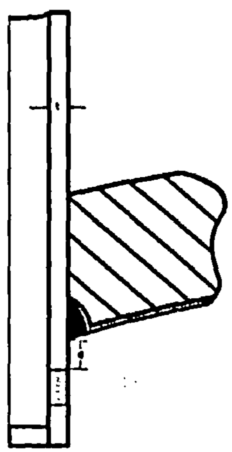
Orientation	Crack Tip Location (d)	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Through Wall	______" Below Weld	Uphill	42.6°						

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	l

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



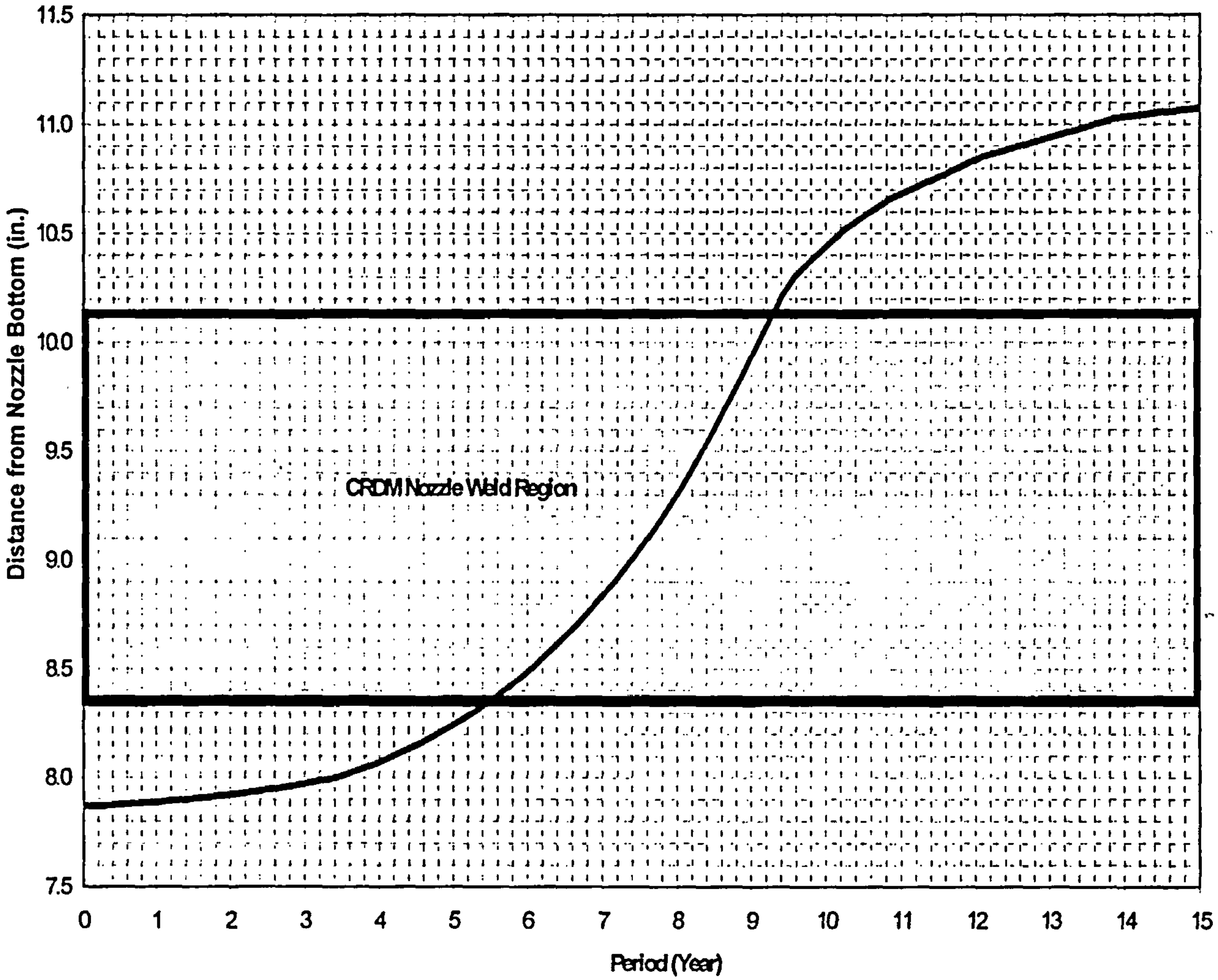


Figure D-18 Through-Wall Axial Flaws Located in the 42.6 Degree Row of Penetrations, Uphill Side - Crack Growth Predictions

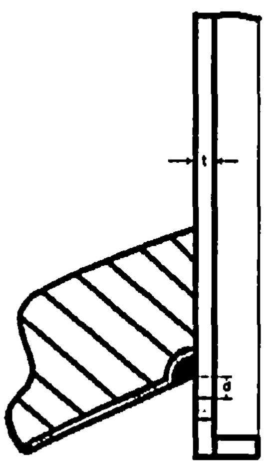
Orientation	Crack Tip Location (d)	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Through Wall	______" Below Weld	Downhill	42.6°						

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	l

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



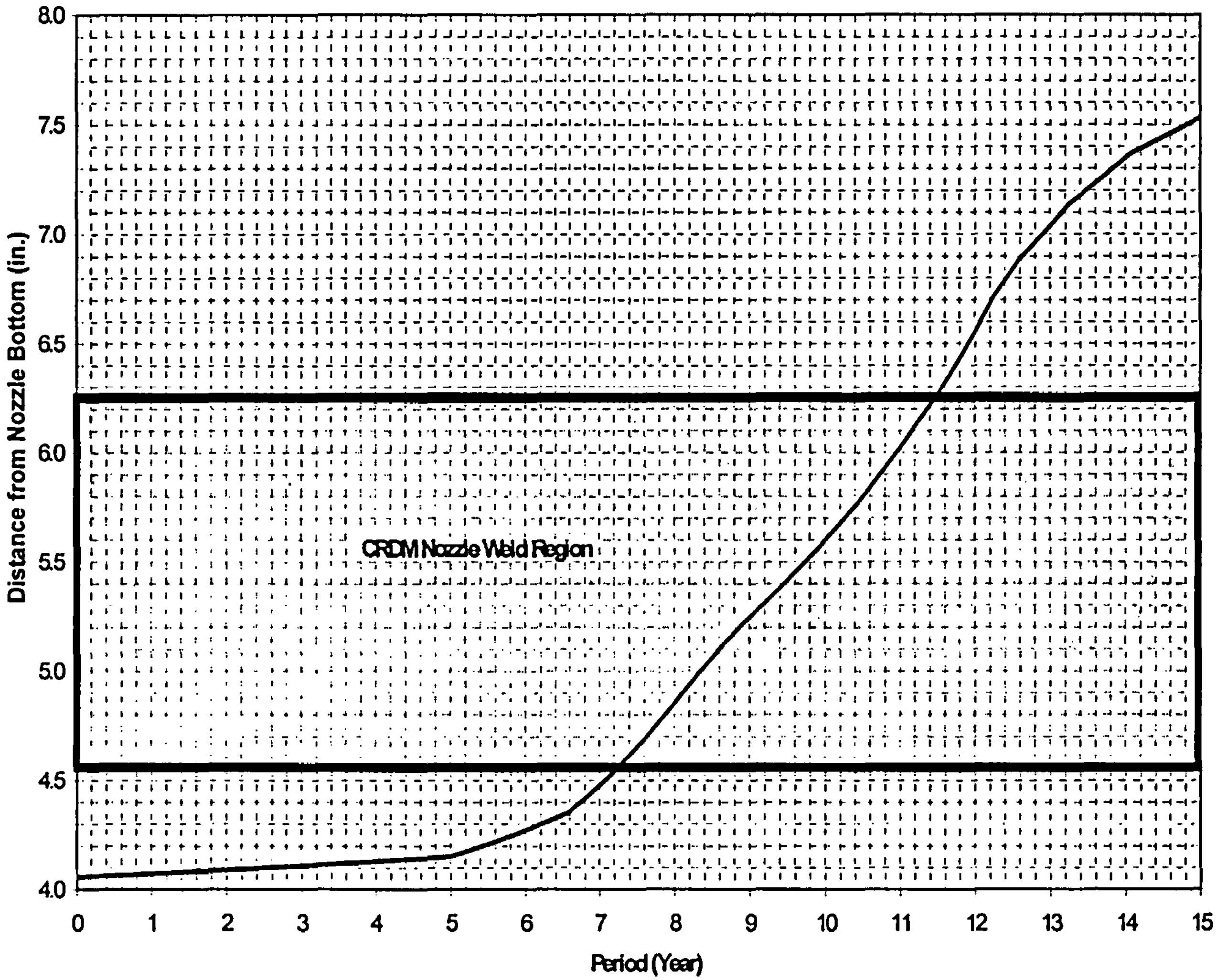


Figure D-19 Through-Wall Axial Flaws Located in the 42.6 Degree Row of Penetrations, Downhill Side - Crack Growth Predictions

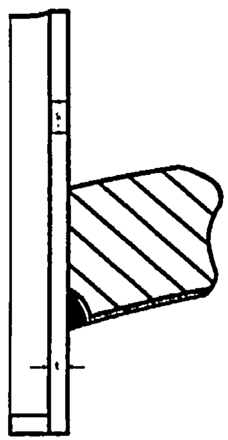
Orientation	Crack Tip Location (d)	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Circum. – Through Wall	Above Weld	Uphill / Downhill							

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	l

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



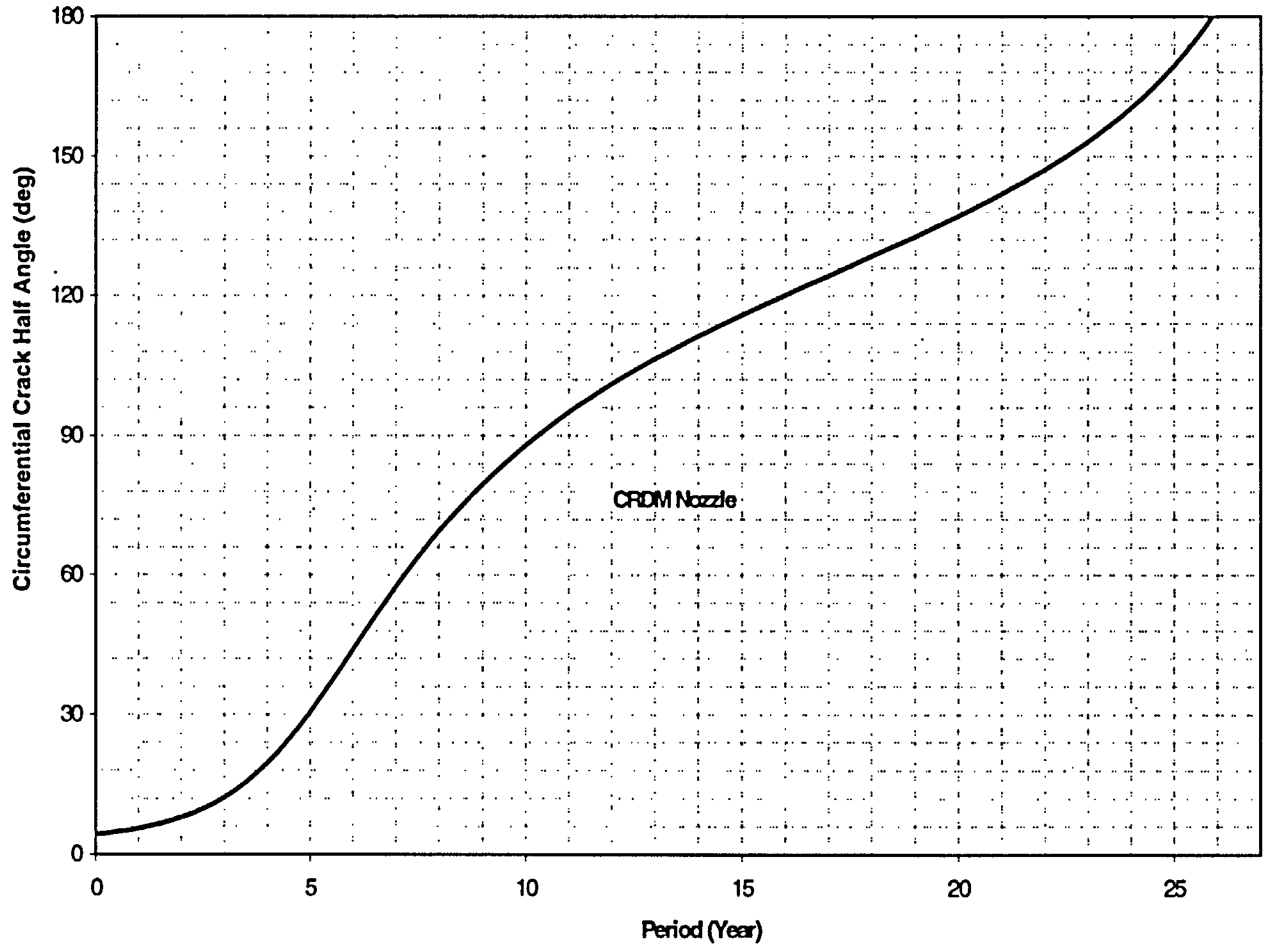


Figure D-20 Through-Wall Circumferential Flaws Near the Top of the Attachment Weld for CRDM Nozzles - Crack Growth Predictions (MRP Factor of 2.0 Included

APPENDIX E

RAI RESPONSES TO RELAXATION FROM ORDER EA-03-009

This appendix contains the Request for Additional Information (RAI) and responses pertaining to Relaxation from Order EA-03-009 for Turkey Point Unit 3 (Docket No. 50-250) documented in letter FPL-03-37, which was electronically approved (see cover letter) [12].

REQUEST FOR ADDITIONAL INFORMATION

RELAXATION FROM ORDER EA-03-009

TURKEY POINT PLANT UNIT 3

DOCKET NO. 50-250

1. In Figures 5-3 through 5-9 of WCAP-16027-P, what is the maximum hoop stress in the nozzle base material greater than one inch from the bottom of the weld? What material properties (i.e., yield strength) were used in these calculations?

2. In Table 2 of the submittal, the Head Vent's leak path data has been marked N/A. How will the assessment of leakage required in Section IV.C.(1)(b)(i) be performed for the Head Vent? Have you considered a surface examination to provide an assessment of the condition of the J-groove weld of the head vent?

3. In Figure 1 of the submittal, the degrees of missed coverage for control rod drive mechanism (CRDM) 67 are listed as 60.27 and 175.79 for a total of 236.06 degrees. In Table 2 of the submittal, a comment for CRDM 67 states "coverage below weld from 343 degrees - 170 degrees." What is the area of missed coverage for this nozzle, how is it determined and how does one reconcile the information provided in the C-scans with the table?

4. Has the crack growth data in Figure 4-4 of WCAP-16027-P (in particular the data marked "Huntington") been normalized to a common temperature (325 C?) or does this figure represent as-measured data?

5. The Order provides for ultrasonic testing (UT) and assessment of leakage, OR surface examination to assess the condition of the vessel head penetration nozzles and J-groove welds. Have you considered supplementing the limited UT examination data for some nozzles (as described in your relaxation request) with surface examinations to provide 100% coverage for each nozzle?

Westinghouse

Westinghouse Electric Company
Nuclear Services
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Pittsburgh, Pennsylvania 15230-0355
USA

Mr. Jimmie L. Perryman, ENG-JB Room D 4466
Turkey Point Project Engineer
Florida Power & Light Company
700 Universe Boulevard
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Juno Beach, Florida 33408-0420

Direct tel: 412-374-6650
Direct fax: 412-374-3451
e-mail: mcdonopj@westinghouse.com

Our ref: FPL-03-37

March 21, 2003

FLORIDA POWER & LIGHT COMPANY
TURKEY POINT UNIT 3
RAI Responses to Relaxation from Order EA-03-009

Dear Mr. Perryman:

Attached please find responses to the Request for Additional Information (RAI) pertaining to Relaxation from Order EA-03-009 for Turkey Point Unit 3 (Docket No. 50-250). These responses pertain to RAI #1 and RAI #4 and have been independently verified in accordance with the Westinghouse QA requirements.

Should you need additional information, please do not hesitate to contact the undersigned.

Sincerely,

WESTINGHOUSE ELECTRIC COMPANY LLC

P. J. McDonough
Customer Projects Manager

Attachment

cc: Bob Tomonto
John Rivera
Joe LaDuca
Paul Roach

Official record electronically approved in EDMS 2000

A BNFL Group company

E-4

(a,c,e)

[ ]

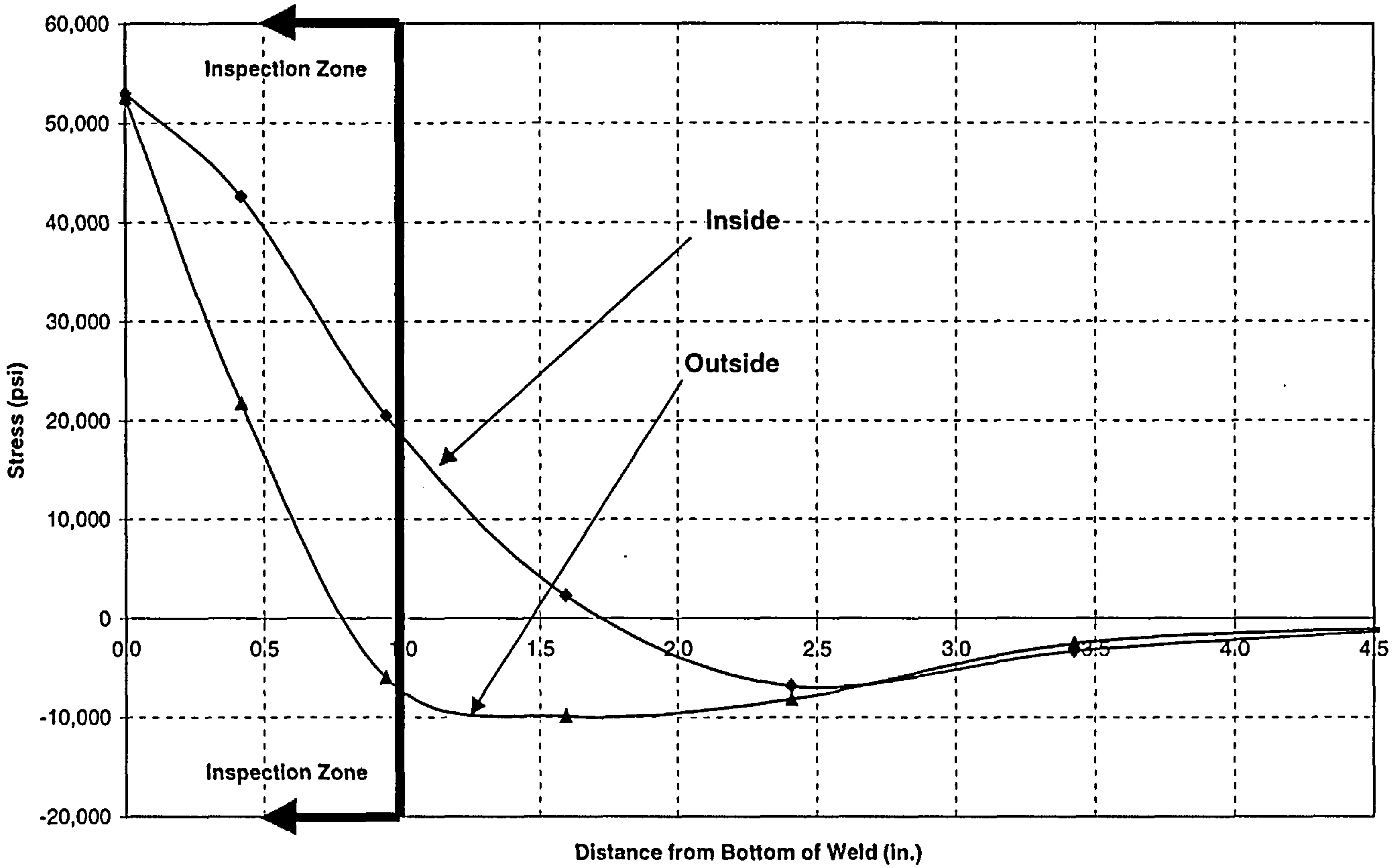

Figure E-1 Hoop Stress in Figure 5-7 vs. Distance from Bottom of Weld, 0 degrees Uphill and Downhill

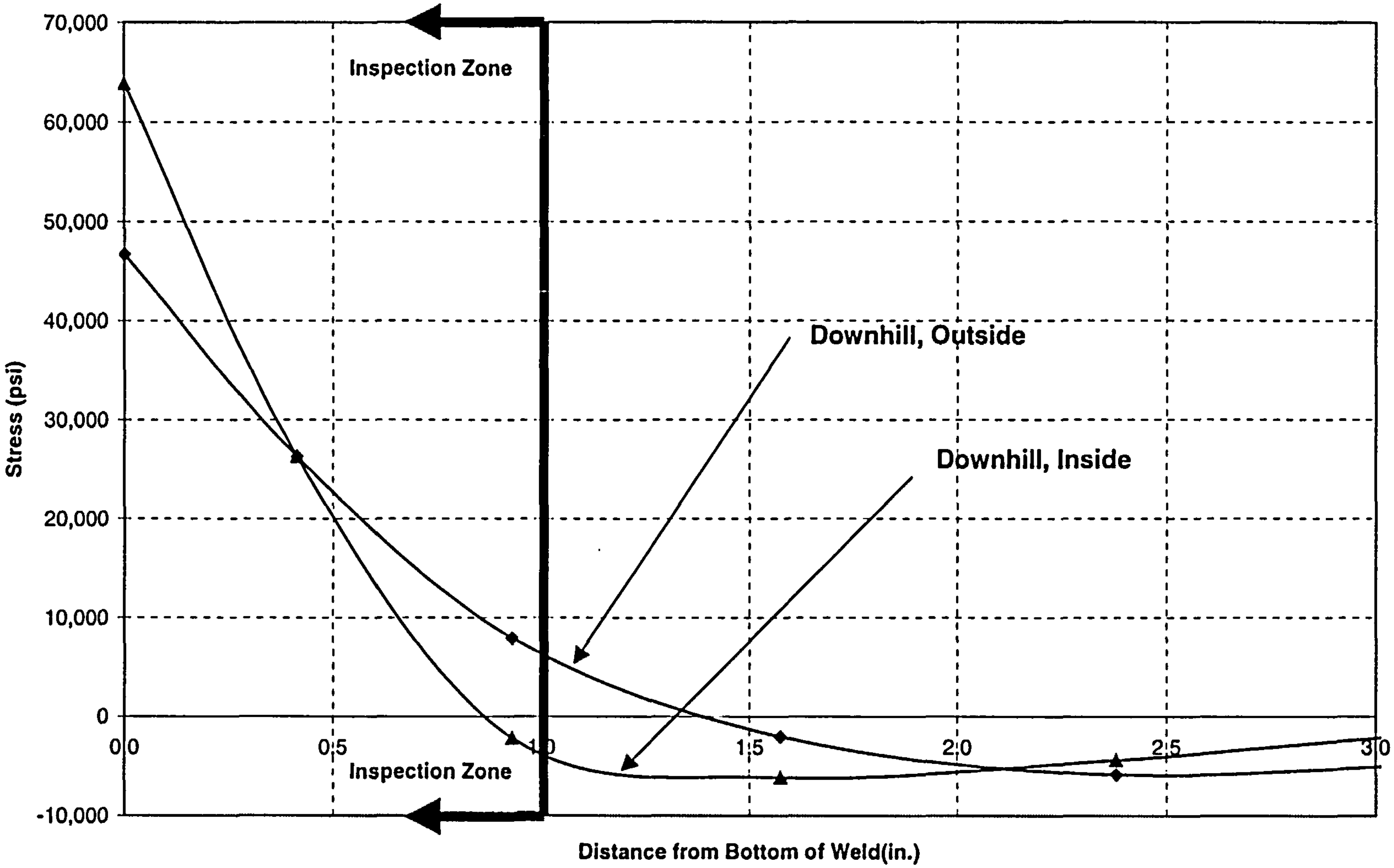

Figure E-2 Hoop Stress in Figure 5-6 vs. Distance from Bottom of Weld, 28.6 degrees Downhill

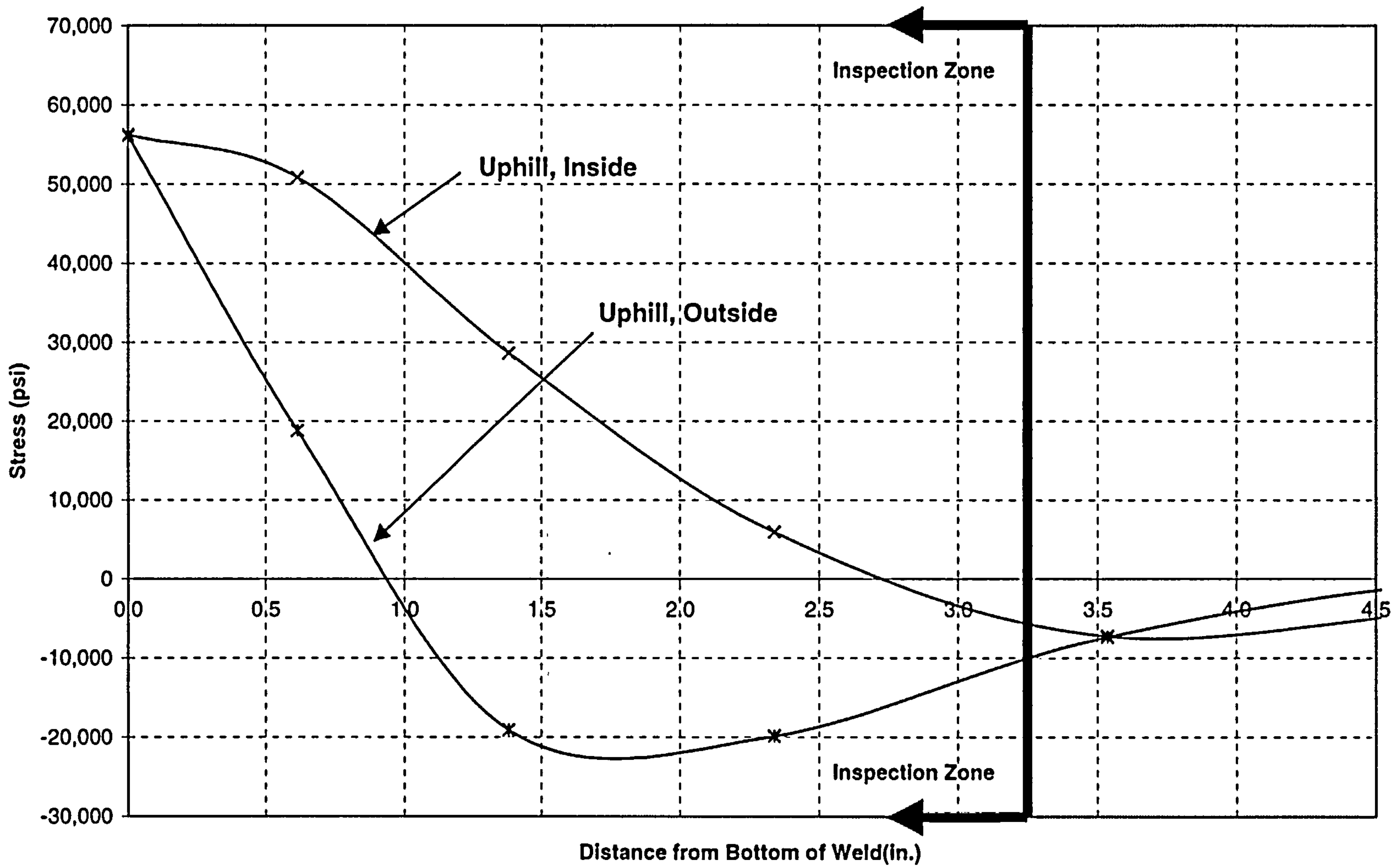

Figure E-3 Hoops Stress in Figure 5-6 vs. Distance from Bottomr of Weld, 28.6 degrees Uphill

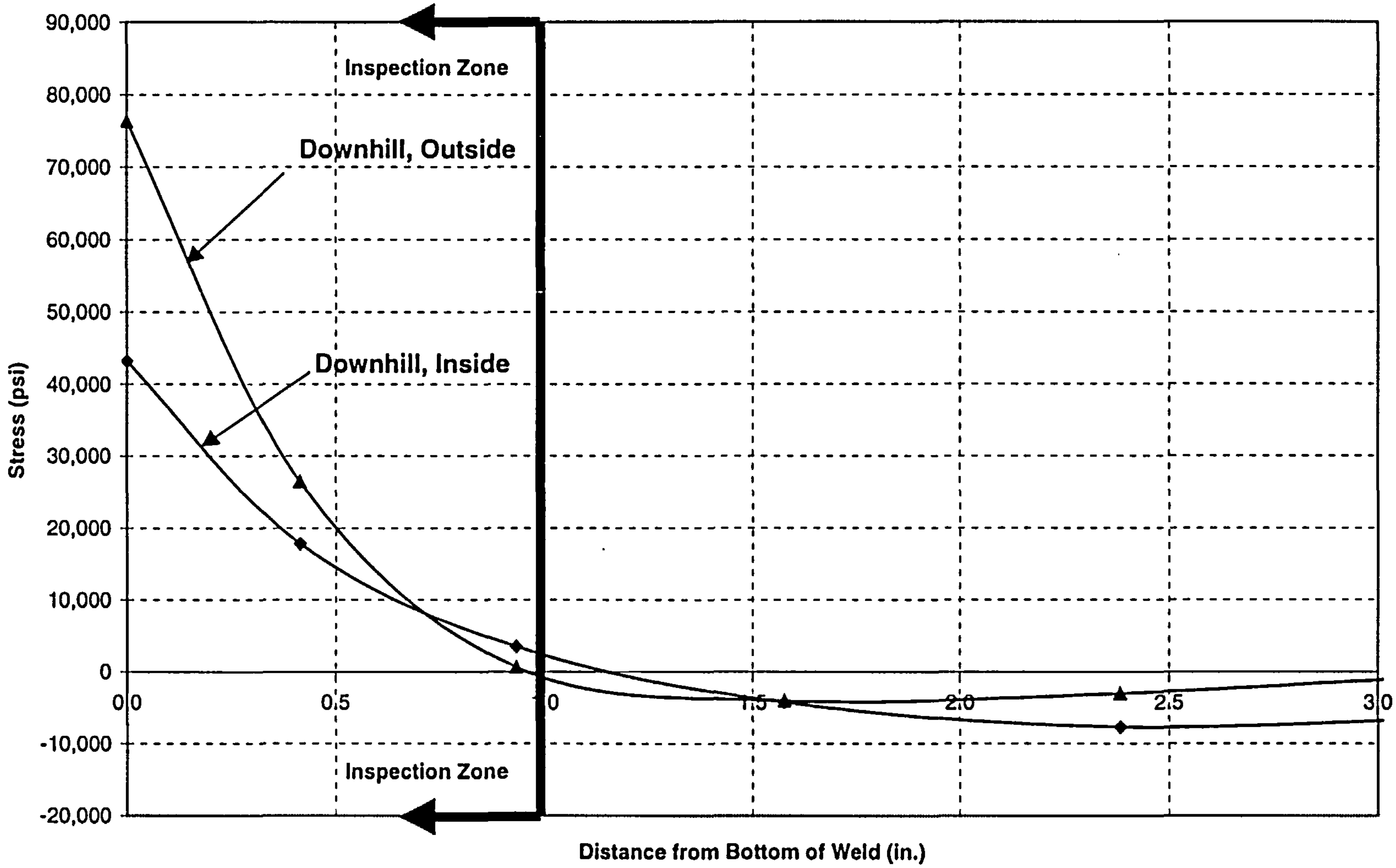

Figure E-4 Hoop Stress in Figure 5-5 vs. Distance from Bottom of Weld, 38.6 degrees Downhill

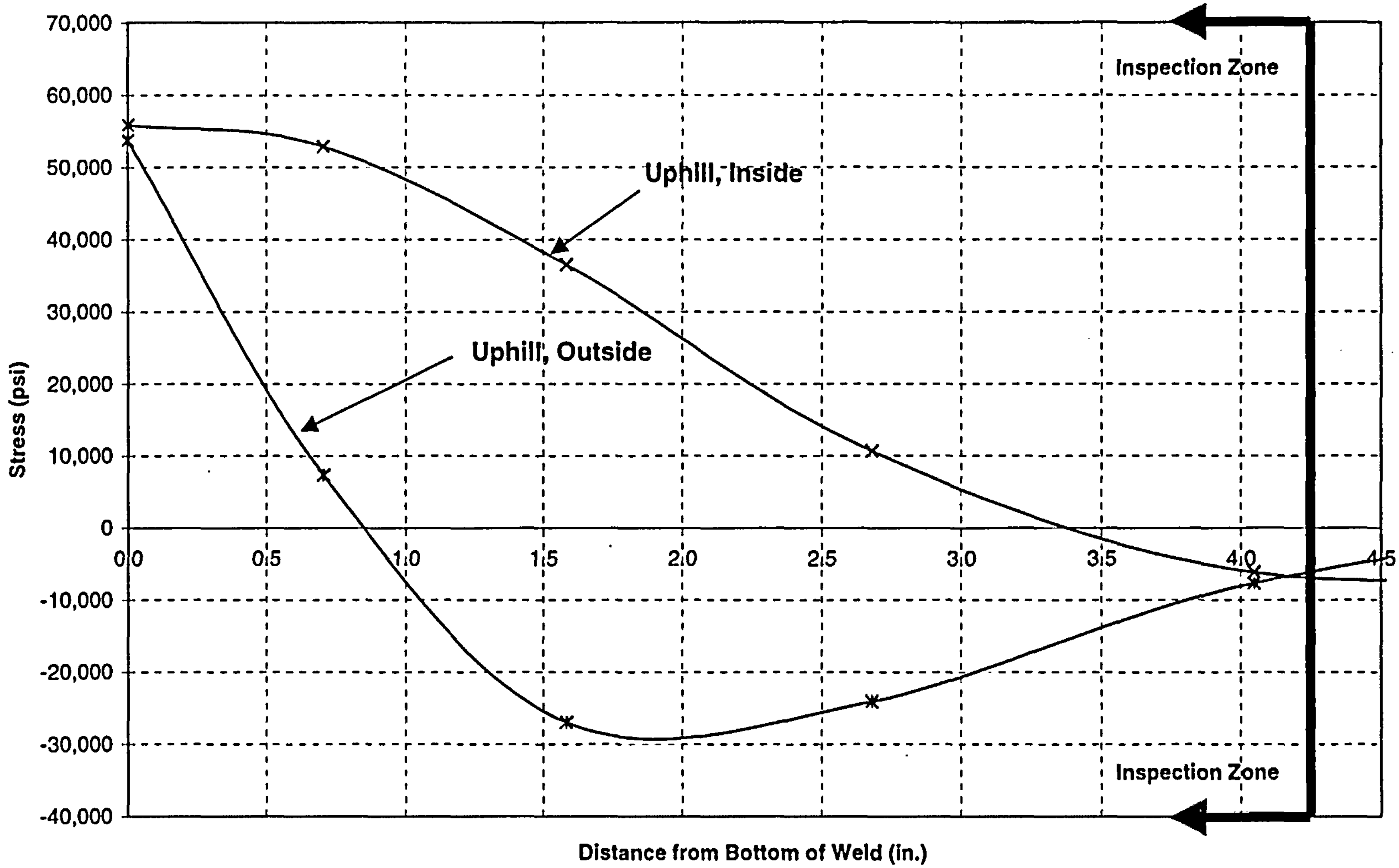

Figure E-5 Hoop Stress in Figure 5-5 vs. Distance from Bottomr of Weld, 38.6 degrees Uphill

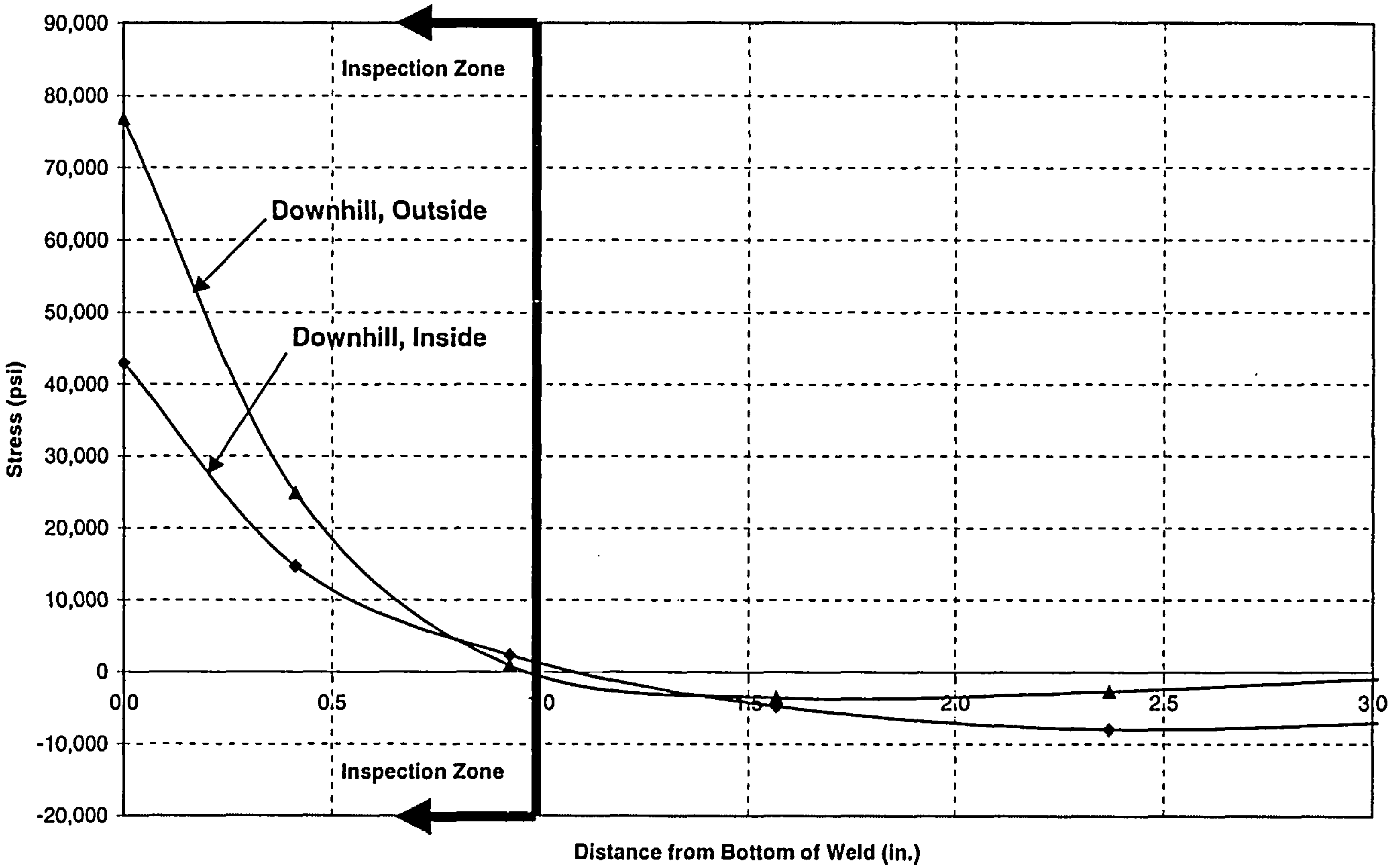

Figure E-6 Hoop Stress in Figure 5-4 vs. Distance from Bottom of Weld, 40.0 degrees Downhill

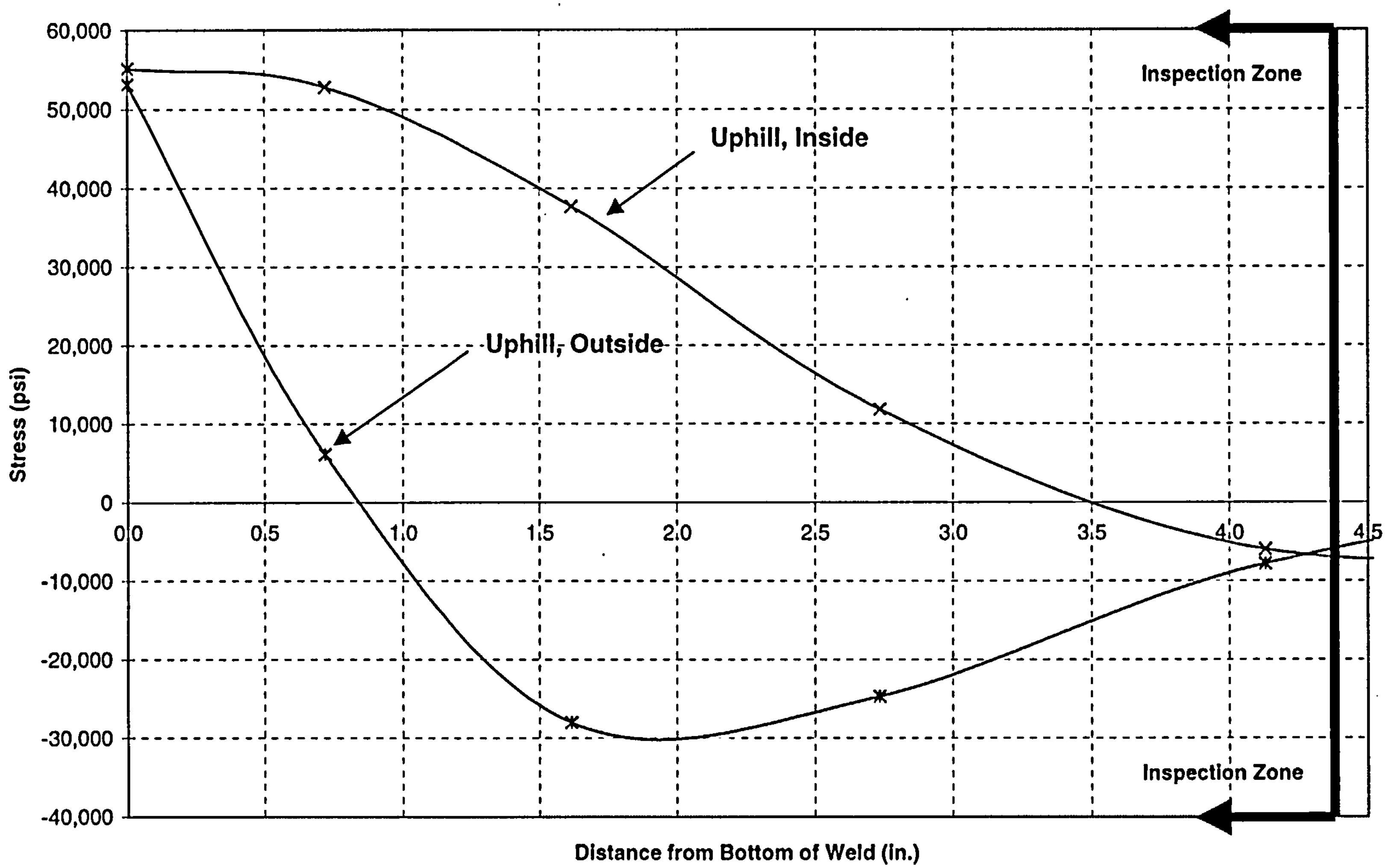

Figure E-7 Hoop Stress in Figure 5-4 vs. Distance from Bottom of Weld, 40.0 degrees Uphill

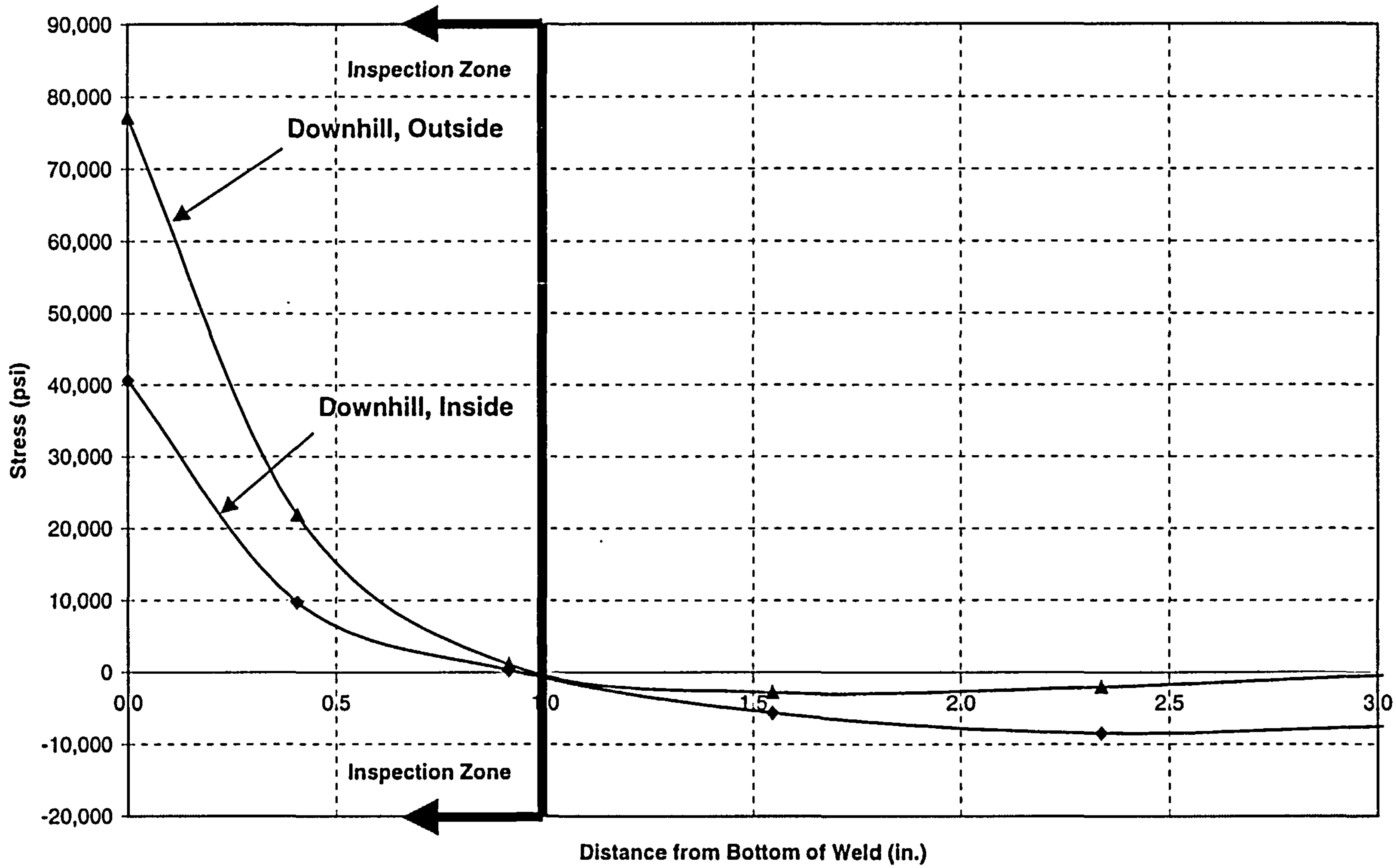

Figure E-8 Hoop Stress in Figure 5-3 vs. Distance from Bottom of Weld, 42.6 degrees Downhill

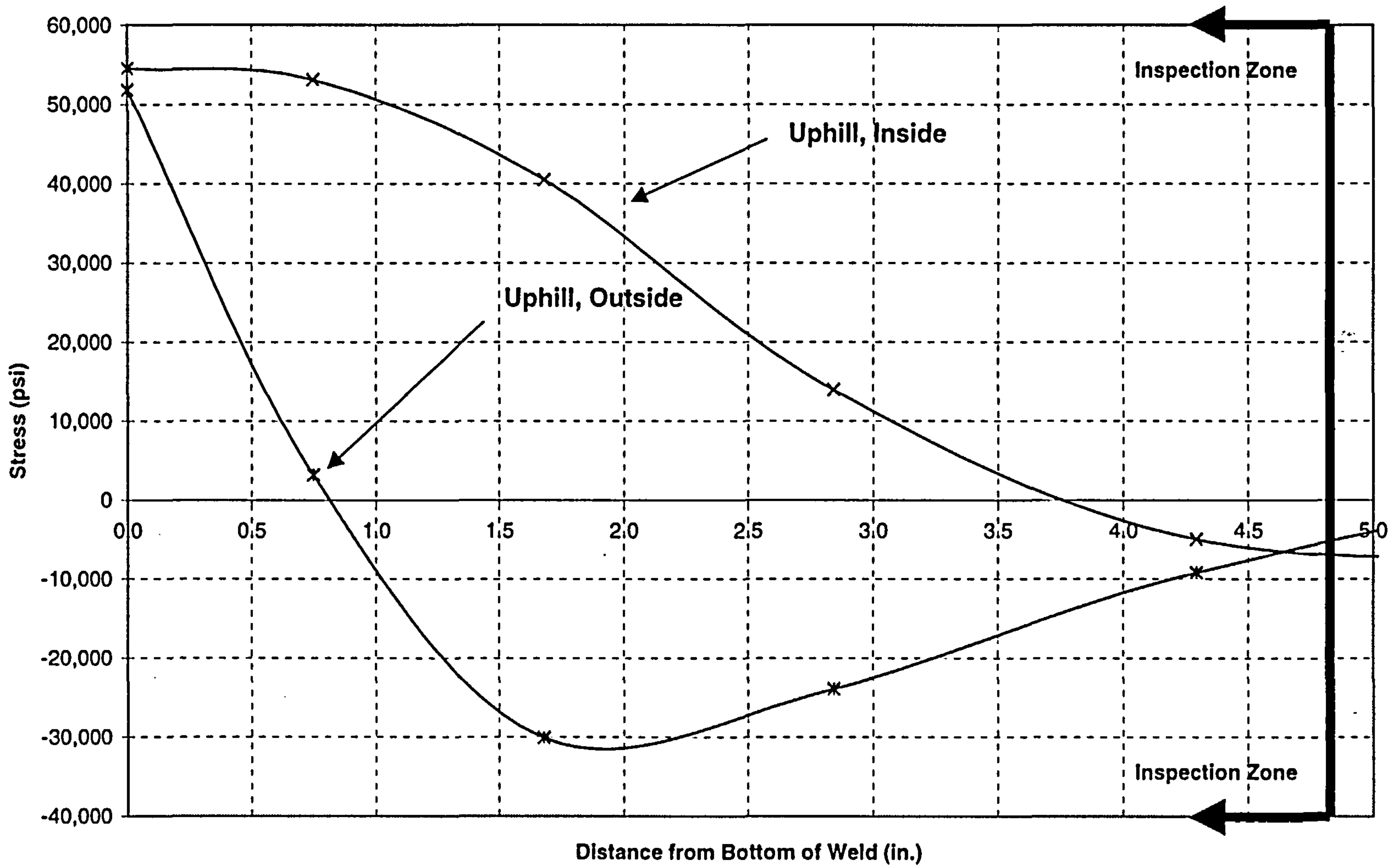

Figure E-9 Hoop Stress in Figure 5-3 vs. Distance from Bottom of Weld, 42.6 degrees Uphill

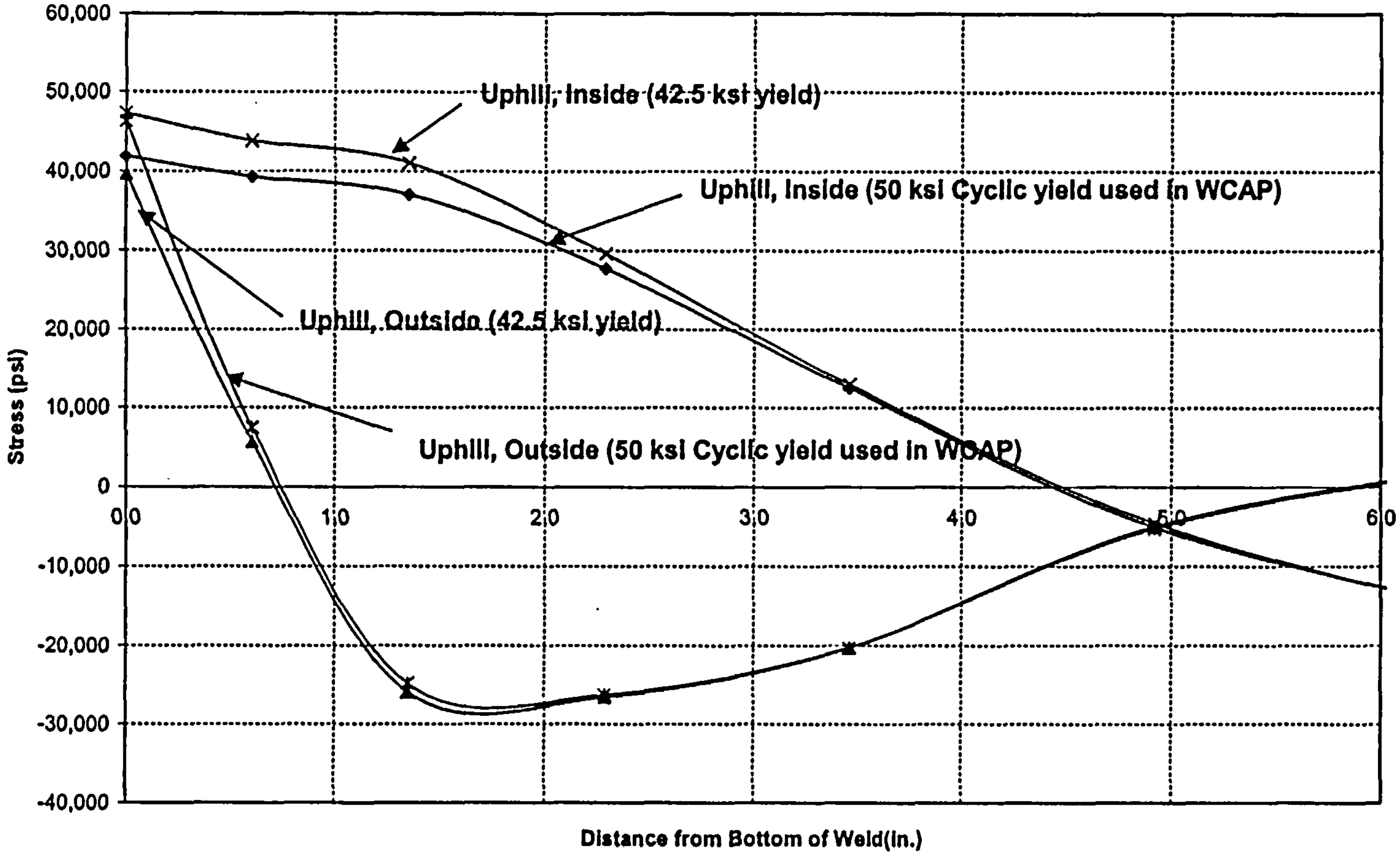

Figure E-10 Hoop Stress vs. Distance from Bottom of Weld, 49.6 degrees Uphill (Note : Results are for a typical plant, not Turkey Point specific)

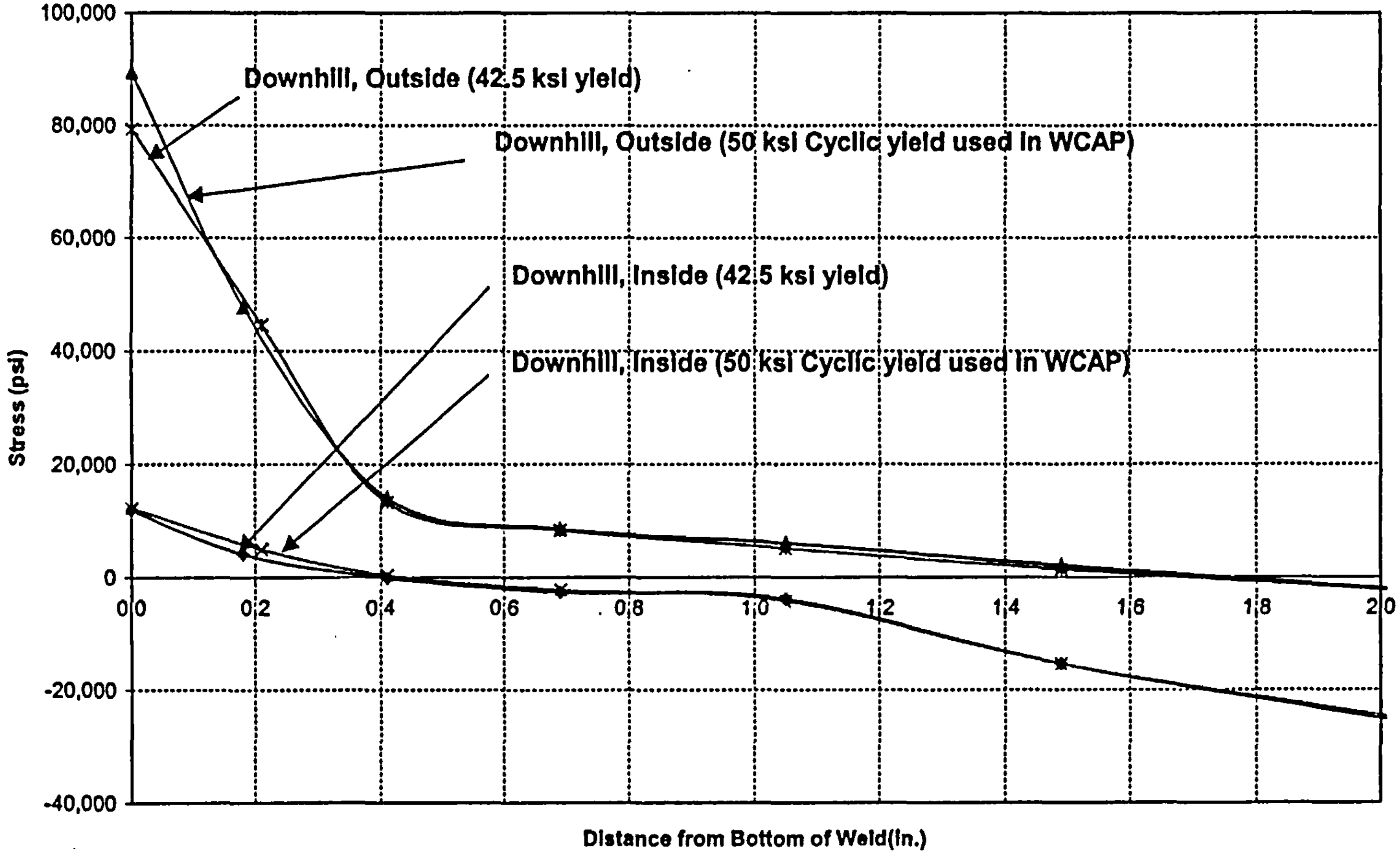

Figure E-11 Hoop Stress vs. Distance from Bottom of Weld, 49.6 degrees Downhill (Note : Results are for a typical plant, not Turkey Point specific)

RAI #4 Has the crack growth data in Figure 4-4 of WCAP-16027-P (in particular the data marked "Huntington") been normalized to a common temperature (325 °C?) or does this figure represent as-measured data?

(a,c,e)

Note that the data have been normalized to a temperature of 325°C. The actual test temperatures are listed in parenthesis after the caption. For example, the Huntington data were obtained at temperatures ranging from 315°C to 331°C.

Figure E-12 Model for PWSCC Growth Rates in Alloy 600 in Primary Water Environments (325°C), With Supporting Data from Standard Steel, Huntington, and Sandvik Materials

APPENDIX F

NRC RESPONSE TO TURKEY POINT UNIT 3 – RELAXATION OF THE REQUIREMENTS OF ORDER (EA-03-009) REGARDING REACTOR PRESSURE VESSEL HEAD INSPECTIONS (TAC NO. MB7990)

The following is the NRC letter approving the request for relaxation of order EA-03-009 [13].

MAR-20-2003 15:08 P.02/07

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

March 20, 2003

Mr. J. A. Stall
Senior Vice President, Nuclear and
Chief Nuclear Officer
Florida Power and Light Company
P.O. Box 14000
Juno Beach, Florida 33408-0420

SUBJECT: TURKEY POINT UNIT 3 — RELAXATION OF THE REQUIREMENTS OF ORDER (EA-03-009) REGARDING REACTOR PRESSURE VESSEL HEAD INSPECTIONS (TAC NO. MB7990)

Dear Mr. Stall:

The U.S. Nuclear Regulatory Commission has approved the enclosed request for relaxation of the specific requirements of Order EA-03-009, requiring specific inspections of the reactor pressure vessel (RPV) and associated penetration nozzles at pressurized water reactors, for Turkey Point Unit 3. This Relaxation is in response to your letter dated March 11, 2003, as supplemented by a letter dated March 14, 2003. Florida Power and Light has requested Relaxation for Turkey Point Unit 3, of the requirements to perform the prescribed ultrasonic testing (UT) inside the tube from 2 inches above the J-groove weld to the bottom of the penetration for nine RPV head penetrations. Specifically, this Relaxation allows the UT examination, with less than full coverage, for nine RPV nozzles. The areas on each nozzle with less than full coverage are located in a non-pressure boundary portion of the nozzle that is greater than 1 inch below the J-groove weld to the bottom of the nozzle. This acceptance is contingent upon one condition described in the enclosed Safety Evaluation report.

If there are any questions concerning this approval, please to contact Ms. Eva Brown at (301) 415-2315.

Sincerely,

Scott W. Moore, Acting Director
Project Directorate II
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Docket No. 50-250

Enclosure: As stated

cc w/encl: See next page

MAR-20-2003 15:09 P.03/07

Mr. J. A. Stall
Florida Power and tight Company

TURKEY POINT PLANT

cc:
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Florida Power & Light Company
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Mr. Rajiv S. Kundalkar
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Juno Beach, FL 33408-0420

MAR-20-2003 15:09 P.04/07

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELAXATION OF FEBRUARY 11.2003. ORDER (EA-03-009)

REACTORPRESSURE VESSEL HEAD INSPECTIONS

FLORIDA POWER AND LIGHT

TURKEY POINT NUCLEAR PLANT, UNIT 3

DOCKET NO. 50-250

1 .0 INTRODUCTION

By letter dated March 11, 2003, as supplemented by a letter dated March 14, 2003, Florida Power and Light (the licensee) submitted a request for relaxation, in accordance with Section IV, paragraph F(2) of Order EA-03-009 for Turkey Point Unit 3, of the requirements contained in Section IV, paragraphs C.(l)(b)(i) of Order EA-03-009 issued by the U.S. Nuclear Regulatory Commission (NRC) staff on February 11, 2003. Relaxation was requested for one 18-month operating cycle. The errata to Order EA-03-009, issued March 14, 2003, do not affect the technical issues raised in the Relaxation request.

The basis for the licensee's request was that compliance with Order EA-03-009 for nine reactor pressure vessel (RPV) head penetrations would result in hardship or unusual difficulty without a compensating increase in the level of quality and safety. The licensee has requested relaxation of the requirements to perform the prescribed ultrasonic testing (UT) inside the tube from 2 inches above the J-groove weld to the bottom of the penetration for nine RPV head penetrations. Specifically, the Relaxation would allow the UT examination, with less than full coverage, for nine RPV nozzles. The areas on each nozzle with less than full coverage are located in a nonpressure boundary portion of the nozzle that is greater than 1 inch below the weld to the bottom of the nozzle.

2.0 REGULATORY EVALUATION

Order EA-03-009, issued on February 11, 2003, requires specific examinations of the RPV head and vessel head penetration (VHP) nozzles of all pressurized water reactor plants. Section IV, paragraph F, of the Order states that requests for Relaxation of the Order associated with specific penetration nozzles will be evaluated by the NRC staff using the procedure for evaluating proposed alternatives to the American Society of Mechanical Engineers Code in accordance with Title 10 of the *Code of Federal Regulations* Section 50.55a(a)(3). Section IV, paragraph F, of the Order states that a request for Relaxation regarding inspection of specific nozzles shall address the following criteria: (1) the proposed alternative(s) for inspection of specific nozzles will provide an acceptable level of quality and safety, or (2) compliance with this Order for specific nozzles would result in hardship or unusual difficulty without a compensating increase in the level of quality and safety.

Turkey Point Unit 3 was determined to have a high susceptibility to primary water stress-corrosion cracking (PWSCC) in. accordance with Section IV, paragraphs A and B, of the ... Order.

3.0 TECHNICAL EVALUATION

3.1 Components for Which Relaxation is Requested

The licensee has requested relaxation of Section IV, paragraph C.(l)(b)(i) of the Order for nine VHP nozzles, including numbers 14, 16, 25, 28, 31, 43, 63, 64, and 67.

3.2 Order Requirements for Which Relaxation is Requested

For Turkey Point Unit 3, and similar plants determined to have a high susceptibility to PWSCC in accordance with Section IV, paragraphs A and B, of the Order, the following inspections are required to be performed every refueling outage in accordance with Section IV, paragraph G.(l) of the Ordar:

(a) Bare metal visual (BMV) examination of 100 percent of the RPV head surface (including 360° around each RPV head penetration nozzle), and

(b) Either:

(i) UT of each RPV head penetration nozzle (i.e., nozzle base material) from 2 inches above the J-groove weld to the bottom of the nozzle and an assessment to determine if leakage has occurred into the interference fit zone, or

(ii) Eddy current testing or dye penetrant testing of the wetted surface of each J-Groove weld and RPV head penetration nozzle base material to at least 2 inches above the J-groove weld.

Footnote 3 of the Order provides specific criteria for examination of repaired VHP nozzles.

3.3 Licensee's Proposed Alternative

The proposed alternate examination is to perform an UT examination to include 2 inches above the weld to at least 1 inch below the weld.

3.4 Licensee's Basis for Relaxation

The licensee stated that gaining access to perform examination of the nine VHP nozzles would result in a hardship or unusual difficulty without a compensating increase in the level of quality and safety. In particular, a physical modification, such as removal of sleeves inside of these nozzles, or the development of new equipment would be required to implement an inspection in accordance with Section IV, paragraph C.(I)(b)(i), of the Order. As described in Attachment 2 of the supplement to the licensee's request dated March 14, 2003, the effect of not performing the inspection for which relaxation is requested is negligible on the level of quality and safety. Due to the low stresses in these portions of the nozzles and the corresponding low crack growth rates, the licensee indicates that there are no concerns with the structural integrity of the VHP nozzles from the unexamined portions of the nozzles addressed in their request.

3.5 Evaluation

The NRC staff's review of this request was based on criterion (2) of paragraph F of Section IV of the Order, which states:

> Compliance with this Order for specific nozzles would result in hardship or unusual difficulty without a compensating increase in the level of quality and safety.

Within the context of the licensee's proposed alternative examination of the RPV penetration nozzles, the licensee has demonstrated the hardship that would result from implementing examinations to the bottom end of these nozzles. The staff agrees that the nozzles' geometry makes inspection of these nozzles in accordance with Order EA-03-009 very difficult and would involve a hardship. This evaluation focuses on the issue of whether there is a compensating increase in the level of quality and safety such that these nozzles should be inspected despite this hardship.

The licensee's request to limit examination of the nozzle base material inner surface to 1 inch below the weld is appropriately supported by the licensee's analysis which demonstrated that no flaw below that portion of the nozzle would propagate to a level adjacent to the J-groove weld within an 18-month operating period. This analysis used the approach described in Footnote 1 of the Order as the criteria to set the necessary height of the surface examination. However, the licensee's analysis uses a crack growth formula from the Electric Power Research Institute Report, "Material Reliability Program (MRP) Crack Growth Rates for Evaluating Primary Water Stress Corrosion Cracking (PWSCC) of Thick Walt Alloy 600 Material (MRP-55), Revision 1" which is different than that described in Footnote 1 of Order EA-03-009. The NRC staff is currently evaluating this report and has not made an assessment regarding the acceptability of the report. Should the NRC staff find the crack growth formula used by the licensee to be unacceptable, the licensee will be required to revise its analysis to incorporate an acceptable crack growth formula.

The safety issues that are addressed by the inspections mandated by Order EA-03-009 are degradation (corrosion) of the low-alloy steel RPV head and ejection of the VHP nozzle due to circumferential cracking of the nozzle above the J-groove weld. The following three items provide reasonable assurance that these safety issues are addressed:

1. The BMV examination performed by the licensee directly demonstrated the integrity of the RPV head and the absence of ongoing degradation of the head.

2. The licensee's analysis, which demonstrates that no flaw located within the unexamined portion of the nozzles (i.e., more than 1 inch below the J-groove weld) would propagate to a level adjacent to the weld within an 18-month operating period, provides sufficient justification that there is a very low likelihood of through wall leakage or possible

degradation of the low-alloy steel RPV head, due to such a flaw, prior to the next inspection.

3. The UT examination of 55 of the 64 RPV head penetration nozzles in accordance with Section IV, paragraph C.(l)(b)(i), of the Order and the remaining nine RPV head penetration nozzles from 2 inches above, the weld to greater than or equal to 1 inch below the weld reasonably demonstrates that the RPV head penetration nozzles are intact throughout the region of inspection. This examination provides reasonable assurance that no circumferential cracking of the nozzle above the J-groove weld is present and no through wall leakage and dsgradation of the RPV head should occur,

The inspections proposed by the licensee combined with an evaluation of the effects of postulated cracks in the areas below 1-inch (e.g., crack growth analysis) provide reasonable assurance of adequate protection of the public health and safety.

3.6 Condition

This authorization has one condition. Should the NRC staff find the crack growth formula described In industry report MRP-55 to be unacceptable, the licensee will be required to revise its analysis that justifies no examination of the nozzle inside diameter surface greater than 1 inch below the J-groove weld.

4.0 CONCLUSION

The NRC staff concludes that inspection of the nine VHP nozzles in accordance with Section IV, paragraph G.(l)(b), of Order EA-03-009, would result in hardship without a compensating increase in the level of quality and safety. Further, the staff concludes that the licensee's proposed alternative examination of nine RPV head penetration nozzles to a level at least one inch below the J-groove weld provides reasonable assurance of the structural integrity of the RPV head, VMP nozzles, and welds. However, the NRC staff notes that this acceptance is based not only on the licensee's arguments, but on the criterion identified herein.

> Should the NRC staff find the crack growth formula described in industry report MRP-55 to be unacceptable, the licensee shall revise its analysis that justifies no examination of the nozzle outside surface more than 1 inch below the J-groove weld,

Therefore the NRC staff finds that inspection of these VHP nozzles in accordance with Section IV, paragraph C.(1)(b), of Order EA-03-009 would result in hardship without a compensating increase in the level of quality and safety, and authorizes, pursuant to Section IV, paragraph F, of Order EA-03-009, the alternative proposed by the licensee for VHP head penetration nozzles numbers 14, 16, 25,28, 31, 43, 63, 64, and 67 at Turkey Point Unit 3,

Principal Contributor: Allen Hiser, NRR

Date: March 20, 2003

TOTAL P.07

L-2003-274

ENCLOSURE 2

Westinghouse

Westinghouse Electric Company
Nuclear Services
P.O. Box 355
Pittsburgh, Pennsylvania 15230-0355
USA

U.S. Nuclear Regulatory Commission
Document Control Desk
Washington, DC 20555-0001

Direct tel: (412) 374-5282
Direct fax: (412) 374-4011
e-mail: Sepp1ha@westinghouse.com

Our ref: CAW-03-1616

April 1, 2003

APPLICATION FOR WITHHOLDING PROPRIETARY
INFORMATION FROM PUBLIC DISCLOSURE

Subject: WCAP-16027-P, "Structural Integrity Evaluation of Reactor Vessel Upper Head Penetrations to Support Continued Operation: Turkey Point Units 3 & 4" (Proprietary)

The proprietary information for which withholding is being requested in the above-referenced report is further identified in Affidavit CAW-03-1616 signed by the owner of the proprietary information, Westinghouse Electric Company LLC. The affidavit, which accompanies this letter, sets forth the basis on which the information may be withheld from public disclosure by the Commission and addresses with specificity the considerations listed in paragraph (b)(4) of 10 CFR Section 2.790 of the Commission's regulations.

Accordingly, this letter authorizes the utilization of the accompanying affidavit by Florida Power & Light Company.

Correspondence with respect to the proprietary aspects of the application for withholding or the Westinghouse affidavit should reference this letter, CAW-03-1616 and should be addressed to the undersigned.

Very truly yours,

H. A. Sepp, Manager
Regulatory and Licensing Engineering

Enclosures

cc: S. J. Collins
G. Shukla/NRR

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF ALLEGHENY:

Before me, the undersigned authority, personally appeared H. A. Sepp, who, being by me duly sworn according to law, deposes and says that he is authorized to execute this Affidavit on behalf of Westinghouse Electric Company LLC ("Westinghouse"), and that the averments of fact set forth in this Affidavit are true and correct to the best of his knowledge, information, and belief:

H. A. Sepp, Manager
Regulatory and Licensing Engineering

Sworn to and subscribed
before me this 2nd day
of April, 2003

Notary Public

SHARON L. FIORI COMMONWEALTH OF PENNSYLVANIA NOTARY PUBLIC

Notarial Seal
Sharon L. Fiori, Notary Public
Monroeville Boro, Allegheny County
My Commission Expires January 29, 2007
Member, Pennsylvania Association Of Notaries

(1) I am Manager, Regulatory and Licensing Engineering, in Nuclear Services, Westinghouse Electric Company LLC ("Westinghouse"), and as such, I have been specifically delegated the function of reviewing the proprietary information sought to be withheld from public disclosure in connection with nuclear power plant licensing and rule making proceedings, and am authorized to apply for its withholding on behalf of the Westinghouse Electric Company LLC.

(2) I am making this Affidavit in conformance with the provisions of 10 CFR Section 2.790 of the Commission's regulations and in conjunction with the Westinghouse application for withholding accompanying this Affidavit.

(3) I have personal knowledge of the criteria and procedures utilized by the Westinghouse Electric Company LLC in designating information as a trade secret, privileged or as confidential commercial or financial information.

(4) Pursuant to the provisions of paragraph (b)(4) of Section 2.790 of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld.

(i) The information sought to be withheld from public disclosure is owned and has been held in confidence by Westinghouse.

(ii) The information is of a type customarily held in confidence by Westinghouse and not customarily disclosed to the public. Westinghouse has a rational basis for determining the types of information customarily held in confidence by it and, in that connection, utilizes a system to determine when and whether to hold certain types of information in confidence. The application of that system and the substance of that system constitutes Westinghouse policy and provides the rational basis required.

Under that system, information is held in confidence if it falls in one or more of several types, the release of which might result in the loss of an existing or potential competitive advantage, as follows:

(a) The information reveals the distinguishing aspects of a process (or component, structure, tool, method, etc.) where prevention of its use by any of

Westinghouse's competitors without license from Westinghouse constitutes a competitive economic advantage over other companies.

(b) It consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), the application of which data secures a competitive economic advantage, e.g., by optimization or improved marketability.

(c) Its use by a competitor would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing a similar product.

(d) It reveals cost or price information, production capacities, budget levels, or commercial strategies of Westinghouse, its customers or suppliers.

(e) It reveals aspects of past, present, or future Westinghouse or customer funded development plans and programs of potential commercial value to Westinghouse.

(f) It contains patentable ideas, for which patent protection may be desirable.

There are sound policy reasons behind the Westinghouse system which include the following:

(a) The use of such information by Westinghouse gives Westinghouse a competitive advantage over its competitors. It is, therefore, withheld from disclosure to protect the Westinghouse competitive position.

(b) It is information that is marketable in many ways. The extent to which such information is available to competitors diminishes the Westinghouse ability to sell products and services involving the use of the information.

(c) Use by our competitor would put Westinghouse at a competitive disadvantage by reducing his expenditure of resources at our expense.

(d) Each component of proprietary information pertinent to a particular competitive advantage is potentially as valuable as the total competitive advantage. If competitors acquire components of proprietary information, any one component may be the key to the entire puzzle, thereby depriving Westinghouse of a competitive advantage.

(e) Unrestricted disclosure would jeopardize the position of prominence of Westinghouse in the world market, and thereby give a market advantage to the competition of those countries.

(f) The Westinghouse capacity to invest corporate assets in research and development depends upon the success in obtaining and maintaining a competitive advantage.

(iii) The information is being transmitted to the Commission in confidence and, under the provisions of 10 CFR Section 2.790, it is to be received in confidence by the Commission.

(iv) The information sought to be protected is not available in public sources or available information has not been previously employed in the same original manner or method to the best of our knowledge and belief.

(v) The proprietary information sought to be withheld in this submittal is that which is appropriately marked in WCAP-16027-P, "Structural Integrity Evaluation of Reactor Vessel Upper Head Penetrations to Support Continued Operation: Turkey Point Units 3 & 4" (Proprietary), dated March 2003 for Turkey Point Units 3 & 4, being transmitted by the Florida Power & Light Company letter and Application for Withholding Proprietary Information from Public Disclosure, to the Document Control Desk. The proprietary information as submitted for use by Westinghouse Electric Company LLC for Turkey Point Units 3 & 4 is expected to be applicable for other licensee submittals in response to certain NRC requirements for justification of the structural integrity of the reactor vessel head penetrations for continued operation.

This information is part of that which will enable Westinghouse to:

(a) Assess the risk with unexamined reactor vessel upper head penetrations.

(b) Assist the customer in obtaining NRC approval.

Further this information has substantial commercial value as follows:

(a) Westinghouse plans to sell the use of similar information to its customers for purposes of meeting NRC requirements for licensing documentation.

(b) Westinghouse can sell support and defense of continued safe operation with the presence of cracks in the reactor vessel upper head penetrations.

(c) The information requested to be withheld reveals the distinguishing aspects of a methodology that was developed by Westinghouse.

Public disclosure of this proprietary information is likely to cause substantial harm to the competitive position of Westinghouse because it would enhance the ability of competitors to provide similar documentation and licensing defense services for commercial power reactors without commensurate expenses. Also, public disclosure of the information would enable others to use the information to meet NRC requirements for licensing documentation without purchasing the right to use the information.

The development of the technology described in part by the information is the result of applying the results of many years of experience in an intensive Westinghouse effort and the expenditure of a considerable sum of money.

In order for competitors of Westinghouse to duplicate this information, similar technical programs would have to be performed and a significant manpower effort, having the requisite talent and experience, would have to be expended.

Further the deponent sayeth not.

PROPRIETARY INFORMATION NOTICE

Transmitted herewith are proprietary and/or non-proprietary versions of documents furnished to the NRC in connection with requests for generic and/or plant-specific review and approval.

In order to conform to the requirements of 10 CFR 2.790 of the Commission's regulations concerning the protection of proprietary information so submitted to the NRC, the information which is proprietary in the proprietary versions is contained within brackets, and where the proprietary information has been deleted in the non-proprietary versions, only the brackets remain (the information that was contained within the brackets in the proprietary versions having been deleted). The justification for claiming the information so designated as proprietary is indicated in both versions by means of lower case letters (a) through (f) located as a superscript immediately following the brackets enclosing each item of information being identified as proprietary or in the margin opposite such information. These lower case letters refer to the types of information Westinghouse customarily holds in confidence identified in Sections (4)(ii)(a) through (4)(ii)(f) of the affidavit accompanying this transmittal pursuant to 10 CFR 2.790(b)(1).

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